This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

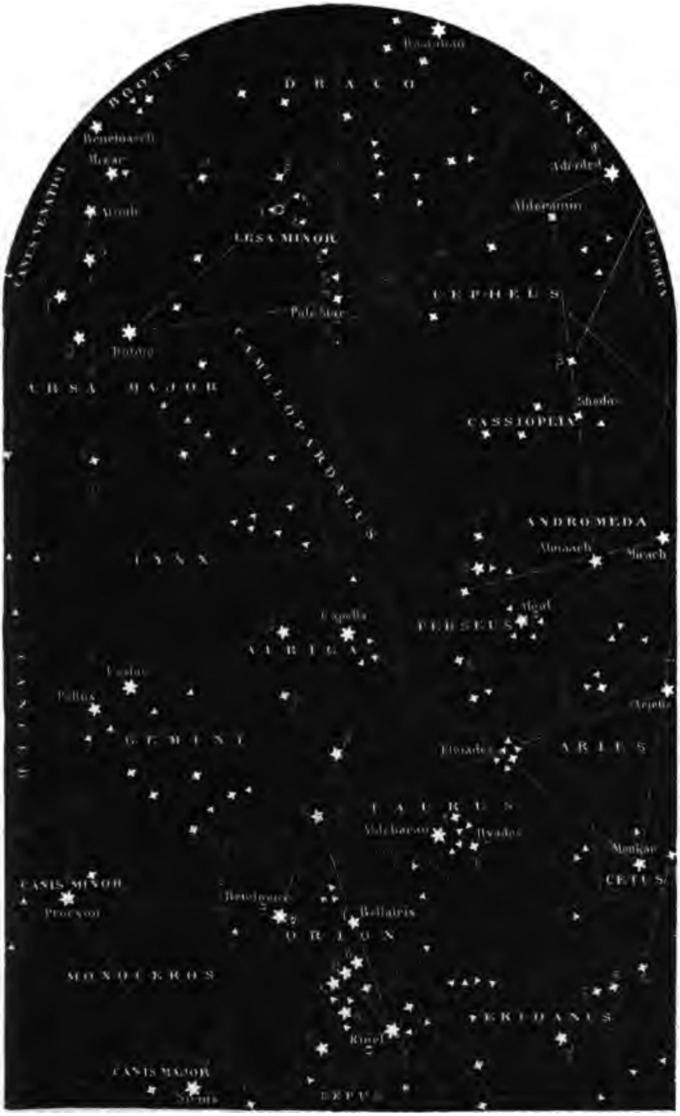
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

PROGRESS & DIFFUSION

BODLEIAN LIBRARY
OXFORD



GENERAL VIEW OF THE REGION ROUND THE STAR CAPELLA, INCLUDING THE CONSTELLATION OF ORION.

POPULAR ASTRONOMY.

BY

DIONYSIUS LARDNER, D.C.L.,

Formerly Professor of Natural Philosophy and Astronomy in University College, London.

CONTAINING:

HOW TO OBSERVE THE HEAVENS.
LATITUDES AND LONGITUDES.
THE EARTH.
THE SUN.
THE MOON.
THE PLANETS, ARE THEY INHABITED?
THE NEW PLANETS.
LE VERRIER AND ADAMS' PLANET.
THE TIDES.
LUNAR INFLUENCES.
THE STELLAR UNIVERSE.

FROM

"THE MUSEUM OF SCIENCE AND ART."

WITH ONE HUNDRED AND NINETEEN ILLUSTRATIONS.

LONDON:
WALTON AND MABERLY,
UPPER GOWER STREET, AND IVY LANE, PATERNOSTER ROW.
1855.

184. b. 8

LONDON:
BRADBURY AND EVANS, PRINTERS, WHITEFRIARS.

CONTENTS.

⁂ As this book is not paged, the figures in the Table of Contents refer to Paragraphs, and not to Pages.

HOW TO OBSERVE THE HEAVENS.

CHAP. I.—1. Spectacle presented by the firmament.—2. Useful observations can be made without astronomical instruments.—3. Apparent motion of the firmament.—4. The meridian.—5. View of the circumpolar region.—6. Permanency of the form of the stellar groups.—7. The celestial sphere. — 8. The celestial poles.—9. Orders of magnitude of the stars.—10. Number of stars of each order.—11. Constellations.—12. Ursa major.—13. Antiquity of the name.—14. Sometimes called Waggon, Wain, or Chariot.—15. Number of stars in it.—16. Proper names of stars.—17. Use of the imaginary figure to express the position of the stars.—18. Ursa minor : the pole star.—19. How it makes a nocturnal clock.—20. Arctic circle : origin of the name.—21. Cassiopeia's chair.—22. Pegasus and Andromeda.—23. Perseus.—24. Auriga.—25. General view of the region of these constellations : Capella, Vega, Adrided, and Altair.—26. Orion.

CHAP. II.—27. Antiquity of the name of Orion.—28. Nebulæ in the constellation Orion.—29. General view of this region of the heavens.—30. Procyon and Sirius.—31. Aldebaran : the Hyades and the Pleiades.—32. The constellations of the zodiac.—33. Use of celestial maps.—34. Use of a celestial globe.—35. To find the place of an object in the heavens.

LATITUDES AND LONGITUDES.

1. Necessary to know our position on the earth.—2. Poles and equator.—3. Parallel of latitude.—4. Meridian of Greenwich.—5. Latitude and longitude.—6. Methods of determining the latitude.—7. By the sun.—8. By stars.—9. Hadley's sextant.—10. Latitude at sea.—11. To find the longitude.—12. Lunar method.—13. Ball signal at Greenwich.

CONTENTS.

THE EARTH.

1. Difficulty of observing the earth as a whole.—2. It appears at first an indefinite flat surface.—3. This disproved by travelling round it.—4. Proof of the curvature of its surface by observation of distant objects at sea.—5. By the Earth's shadow projected on the Moon.—6. Inequalities of surface, such as mountains and valleys, insignificant.—7. Magnitude of Earth, how ascertained.—8. Length of a degree of latitude.—9-10. Illustrations of the Earth's magnitude.—11. Is the Earth at rest?—12. Apparent motion of the firmament.—13. Origin of the word "Universe."—14. This apparent motion may not be real—may arise from the rotation of the Earth.—15. How such a rotation would produce it.—16. Poles.—17. Equator.—18. Hemispheres.—19. Meridians.—20. Which of the two rotations is the more probable?—21. Rotation of the universe impossible.—22. Simplicity of the supposed rotation of the globe.—23. Direct proofs of this motion.—24. Foucault's experiment.—25. Its analogy to the planets.—26. Conclusion as to the globular form of the earth requires modification.—27. All human knowledge tentative and approximative.—28. Rotation not compatible with the exact globular form.—29. Centrifugal force of the Earth's rotation.—30. The globe rotating would assume the form of an oblate spheroid.—31. The degree of ellipticity would vary with the velocity of rotation.—32. Experimental illustration.—33. Ellipticity corresponding to the diurnal rotation.—34. How these circumstances affect the actual state of the Earth.—35. Form of a terrestrial meridian.—36. Dimensions of the terrestrial spheroid.—37. Its departure from an exact globe very small.—38. Its density and mass.—39. Determined by Cavendish and Maskelyne.—40. Its total weight.

THE SUN.

1. An object of great interest.—2. Its distance.—3. Magnitude.—4. Illustrations.—5. Its volume.—6. Mass or weight.—7. How ascertained.—8. Application of this principle.—9. Its density.—10. Form and rotation.—11. Determined by the appearance of spots.—12. Discovery of Solar spots.—13. Their great magnitude.—14. Their rapid changes.—15. Hypotheses to explain them.—16. They are excavations in the luminous coating.—17. Their prevalence varies.—18. Observations upon them.—19. Their dimensions.—20. Facules and lucules.—21. Physical state of the Solar surface.—22. Luminous coating is gaseous.—23. Gaseous atmosphere outside it.—24. Effects of such an atmosphere on radiation.—25. Hypothesis of Sir J. Herschel.—26. Intensity of heat at Sun's surface.—27. Supposed source of heat.

CONTENTS.

THE MOON.

1. Interest with which the moon is regarded, and influences with which it has been invested by the popular mind.—2. Its distance.—3. Its orbit.—4. Its magnitude.—5. Its rotation. — 6. Conjunction. — 7. Quadrature.—8. Opposition.—9-11. Tests of an atmosphere.—12-13. None exists on the moon.—14. No liquids.—15. No diffusion of solar light.—16. Appearance of earth seen from moon.—17. It would have belts.—18. Geographical features and its rotation would be visible through the clouds.—19. Moonlight neither warm nor cold.—20. Moon's physical condition.—21. Thickly covered with mountains.—22. Selenographical discoveries of Beer and Mädler.—23. Vast extent and diameter of the lunar mountains.—24. Circular chains.—25. Description of Tycho.—26. Heights of lunar mountains.—27. Observations of Lord Rosse.—28. Moon not inhabited.

THE PLANETS: ARE THEY INHABITED WORLDS?

Chap. I.—1. Aspect of the firmament.—2. Direct evidence on this question not obtained by the telescope.—3. Telescope diminishes distance.—4. Evidence from analogy extremely cogent.—5. Consideration of the terrestrial planets.—6. Circumstances which render the earth habitable.—7. Like circumstances to be looked for in the planets.—8. Similarity of position and motion of terrestrial planets.—9. Uniformly supplied with light and heat.—10. Objection of inequality of distance answered.—11. By the effect of atmosphere.—12. Different degrees of light on the planets.—13. Structure of the eye.—14. Its adaptation to different distances.—15. Adaptation of strength of organised creatures to their weight.—16. Adaptation of the rotation of the earth to this organisation.—17. Floral clock of Linnæus.—18. Time of rotation not the consequence of a physical law.—19. Rotation of the other planets.—20. Of Mars.—21. Of Venus and Mercury.—22. Their close analogy to the earth.—23. Inclination of the earth's axis.—24. Produces the seasons.—25. Like provision in the other planets.—26. The atmosphere.

Chap. II.—1. Uses of an atmosphere—colour of sky.—2. Its effects on temperature.—3. Planetary atmospheres observable.—4. Clouds visible in them.—5. Hence rain, hail, and snow.—6. Winds manifested on the planets.—7. Clouds on Mercury, Venus, and Mars.—8. Continents and oceans.—9. Effect of gravity on planets.—10. Its relation to organised beings.—11. Adaptation of organised beings to the force of gravity.—12. Gravity on Mercury, Venus, and Mars.—13. Solar system.—Planets.—14. Number of planets—groups.—15. Inner group — the twenty-five grouped round the sun.—16. The outer group—Jupiter, Saturn, Uranus, and Neptune.—17. Their distances from the sun, from each other, and from the earth.—18. Apparent diameters of Sun's disk as seen from these planets—Sun's light and heat.—19. Question of habitability of these planets considered in reference to Sun's light and heat.—20. Great comparative magnitude of these planets—Their volumes—Question of habitability continued.—21. Proportionate population, if inhabited.—22. Investigation of physical causes incompatible with their being habitable globes.—23. Application of such causes to Jupiter, and reasoning thereon—Necessity of organised world being different from that on the earth.—24. Comparative volume and density of the Earth and Jupiter.—25. Comparison of relative quantities of gravitating matter in Saturn, Uranus, and Neptune, and in the Earth—and of density.—26. Comparative weights of bodies placed upon such planets and on the Earth.—27. General results of inquiry as to the habitability of these planets.—28. Atmosphere of these planets.—29. Their diurnal revolution—General observations on rotation and their results—Position of axis of rotation.

CHAP. III.—1. Diurnal rotation of Uranus.—2. Inclination of the axes and limitation of the seasons on the Major planets.—3. Jovian zones and climates.—4. Saturnian. —5. Short days and nights of Major planets.—6. Lightness of their materials.—7. Oceans and seas must consist of a liquid lighter than water.—8. Jovian, Saturnian and Uranian years.—9. Effects of diurnal rotation on the distribution of clouds.—10. These effects more conspicuous in the Major planets.—11. Manifested by the belts.—12. Telescopic appearance of Jupiter.—13. Herschel and Mädler's telescopic views of Jupiter.—14. Jupiter elliptical in form.—15. Discovery of Jupiter's moons.—16. Short months.—17. Lunar eclipses. —18. Telescopic appearance of Jupiter's satellites.—19. As seen from Jupiter.—20. The Saturnian system. — 21. Atmosphere and moons.

CHAP. IV.—1. Apparent magnitudes of the moons as seen from Saturn.—2. Their phases—Short Saturnian months.—3. Solar and lunar eclipses.—4. Discovery of the rings.—5. Phases of the rings as seen from the earth.—6. Their appearance when seen edgeways in 1848—Schmidt's drawings of them.—7. Mountains upon them.—8. Their dimensions.—9. Discovery of the obscure semi-reflective rings.—10. Dawes' telescopic view of the planet and rings.—11. Appearance of the rings as seen from Saturn.—12. Errors committed on this subject by Bode, Herschel, Mädler, and others.—13. Correction of these errors.—14. Appearance of rings will vary with the latitude of the observer. — 15. Illustrative diagrams.—16. Recapitulation. —17. No difficulty can arise in admitting the possibility of differently organised tribes on the different planets. —18. The sun, its physical character incompatible with habitability.—19. The moon not habitable. —20. Nor the satellites. — 21. Comets not habitable.—22. The planetoids or asteroids.

THE NEW PLANETS.

1. Discovery of these planets.—2. The old planets.—3. Numerical law of their distances.—4. A missing planet. — 5. Conjecture of Professor Bode.—6. Discovery of Ceres.—7. Of Pallas.—8. Theory of Dr. Olbers—a broken planet.—9. Discovery of Juno.—10. Of

Vesta.—11. Rapid discovery of the others.—12. Table of the group.—13. Circumstances corroborating the theory of Dr. Olbers.—14. Amateur astronomers.—15. Minute bulk of these planets.—16. Corroboratory of Dr. Olbers' theory.—17. Force of gravity upon them.

LE VERRIER AND ADAMS' PLANET.

1. Surprise excited by the discovery.—2. How a body may be discovered without seeking it.—3. Generalisation of the principle.—4. Its application to the case of Neptune.—5. Condition of the solar system before the discovery.—6. Observed disturbances of Uranus.—7. Great regularity of these effects.—8. How they would be produced by a more distant planet.—9. Calculations of Le Verrier and Adams.—10. Elements of the sought planet according to these geometers.—11. Its actual discovery.—12. Its corrected elements.—13. Discrepancies between the actual and predicted elements explained.—14. Comparison of the effects of the real and predicted planets.—15. The discovery not to be ascribed to chance.—16. The period of Neptune computed.—17. Computation of his distance.—18. Its prodigious orbital motion.—19. Illustrated by a railway train.—20. Its magnitude.—21. Its satellite.—22. Its weight. —23. Its bulk.—24. The sun's light and heat upon it. —25. The sun's apparent diameter seen from it.—26. Its suspected ring.

THE TIDES.

1. Their correspondence with the lunar phases known at an early period.—2. Erroneous notions prevalent as to their causes.—3. Not caused by the moon's attraction.—4. But by the inequality of its attraction.—5. Calculation of this inequality. — 6. Solar tides. —7. Difference between the power of the sun and moon to produce a tide.—8. Spring and neap tides. — 9. Why the tides are not directly under the moon.—10. Establishment of the port.—11. Effects of the form of the coasts upon the local tides. —12. Dr. Whewell's analysis of the progress of the tidal wave.—13. Age of the tide.—14. Velocity of the tide.—15. Undulations.—16. Motion of the crest of a wave.—17. Range of the tide.—18. How affected by the weather.

LUNAR INFLUENCES.

1. Popular opinions on Lunar Influences.—2. Red moon.—3. Time for felling timber.—4. Supposed Lunar Influences on vegetables.—5. On the complexion.— 6. On putrefaction.—7. On shell fish.—8. On the marrow of animals.—9. On the weight of the human body.—10. On births.—11. On incubation.—12. On mental derangement and

other human maladies—Instances of this supposed influence during eclipse given by Faber and Ramazzini—Amusing anecdote of a village curé near Paris—Examples of Vallisnieri and Bacon—Observations and examples of Menuret, Hoffmann, Dr. Mead, Pyson, and Dr. Gall.—13. Difficulty of showing fallacy of these opinions by reasoning or proof—Dr. Olbers' partial refutation of them—Arago's opinion on them.—14. General conclusion that few of these influences have any foundation in fact.

THE STELLAR UNIVERSE.

Chap. I.—1. Retrospect of the solar system.—2. Inquiries beyond its limits. — 3. This system surrounded by an extensive void.—4. This proved by the absence of external perturbations.—5. And by comets, which are feelers of the system. — 6. Where then is the vast multitude of stars which appear in the firmament?—7. Absence of apparent parallax.—8. Illustration of the effects of parallax. — 9. Its apparent absence favoured the Ptolemaic system.—10. Effects of parallax explained. — 11. Parallax of the planets visible.

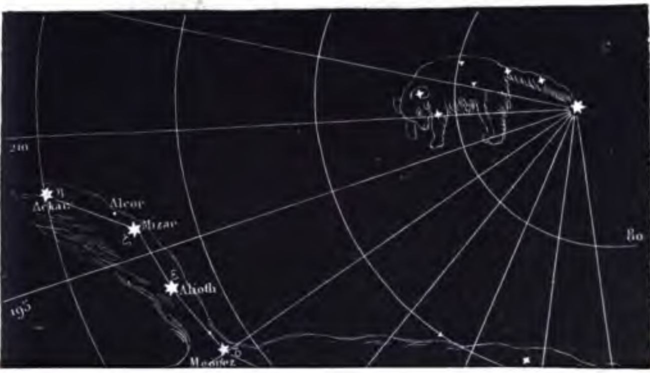
Chap. II.—12. Absence of parallax obstructed the acceptance of the Copernican system.—13. Immense distance of stars inferred from its minuteness or absence.—14. Its greatest possible magnitude.—15. Distances of stars inferred.—16. Use of the motion of light as a modulus of this distance. — 17. Methods of ascertaining the parallax.—18. Parallax of α Centauri.—19. Parallax of nine principal stars.—20. The vacuum surrounding the solar system necessary to cosmical order.—21. Classification of stars by magnitude, arbitrary.—22. Fractional magnitudes.—23. Number of stars of each magnitude.—24. Total number of stars in the firmament.—25. Varieties of magnitude chiefly caused by difference of distance.—26. Stars as distant from each other as from the sun.—27. Telescopes do not magnify them. — 28. Absence of a disc proved by their occultations.—29. Meaning of the term magnitude as applied to the stars.—30. Why the stars may be rendered imperceptible by their distance.—31. Real magnitudes of the stars.—32. Application of photometers or astrometers.—33. Comparison of the sun's light with that of a star.—34. Relative real magnitudes of the sun and a star estimated.—35. Comparative magnitude of the sun and the dog-star.—36. Vast use of the telescope in stellar observations.—37. Its power to increase the apparent splendour of a star explained.

Chap. III.—38. Telescopic stars.—39. Space-penetrating power of the telescope.—40. Vast distances of small telescopic stars.—PERIODIC STARS: 41. Stars of variable lustre.—42. Remarkable stars of this kind in Cetus and Perseus.—43. Table of periodic stars.—44. Hypothesis to explain periodic stars.—TEMPORARY STARS: 45. Such stars seen in ancient times.—46. Star discovered by Mr. Hind.—47. Missing stars.—DOUBLE STARS: 48. Researches of Sir W. and Sir J. Herschel.—49. Stars optically double.—50. This supposition not admissible. — 51. Refuted by the proper motion.—52. Classification of double stars.— 53. Table of double stars.—54. Coloured double stars. — 55. Triple and other multiple stars.—56. Attempt to discover parallax by double stars. — 57. Observations of Sir W. Herschel.

CHAP. IV.—58. His discovery of binary stars.—59. Gravitation of the stars.—60. Star moving round star.—61. Table of binary stars. —62. Case of γ Virginis.—63. System revolving round system. —PROPER MOTION OF STARS: 64. The sun not a fixed centre.—65. Phenomena indicating its motion. —66. Direction of the sun's motion. —67. Its velocity.—68. Its probable centre.—THE FORM AND DIMENSIONS OF THE MASS OF STARS WHICH COMPOSE THE FIRMAMENT: 69. Distribution of the stars on the firmament.—70. Galactic circle and poles. — 71. Variation of stellar density.—72. Struve's analysis of Herschel's observations.—73. The milky way.—74. It consists of innumerable stars crowded together. —75. Probable form of the stratum of stars in which the sun is placed.

CHAP. V.—STELLAR CLUSTERS AND NEBULÆ: 76. The stars of the firmament a stellar cluster. — 77. Such clusters innumerable. — 78. Their distribution on the firmament.—79. Their constitution.— 80. Their apparent and real forms. —81. Nebulæ.—82. Double nebulæ.— 83. Planetary nebulæ.— 84. Annular nebulæ.—85. Spiral nebulæ.

CHAP. VI.—Spiral nebulæ (continued). —86. Number of nebulæ. —87. The Dumb-Bell nebula as observed by Sir J. Herschel and Lord Rosse.— 88. Various nebulæ figured by the same observers.—89. Large irregular nebulæ.—90. Rich cluster in the Centaur.—91. The great nebulæ in Orion.—92. The great nebula in Argo. — 93. Magellanic clouds.



Errata in "How to Observe the Heavens."

Section 26, line 13, *for* "December" *read* "June."
,, ,, ,, 16, ,, "June" ,, "December."
,, ,, ,, 19, ,, "summer" ,, "winter."
,, ,, ,, 20, ,, "latter" ,, "early."
Section 29, ,, 6, ,, "June" ,, "December."

In "Stellar Universe."

Section 1, line 16, *for* "seven" *read* "eight."

Fig. 2.—CONSTELLATIONS OF THE GREATER AND LESSER BEAR, AND THE POLE STAR.

HOW TO OBSERVE THE HEAVENS.

◆

CHAPTER I.

1. Spectacle presented by the firmament.—2. Useful observations can be made without astronomical instruments.—3. Apparent motion of the firmament.—4. The meridian.—5. View of the circumpolar region. —6. Permanency of the form of the stellar groups.—7. The celestial sphere.—8. The celestial poles.—9. Orders of magnitude of the stars. —10. Number of stars of each order.—11. Constellations.—12. Ursa major.—13. Antiquity of the name.—14. Sometimes called Waggon, Wain, or Chariot.—15. Number of stars in it.—16. Proper names of

stars.—17. Use of the imaginary figure to express the position of the stars.—18. Ursa minor: the pole star.—19. How it makes a nocturnal clock.—20. Arctic circle: origin of the name.—21. Cassiopeia's chair.—22. Pegasus and Andromeda.—23. Perseus.—24. Auriga.—25. General view of the region of these constellations: Capella, Vega, Adrided, and Altair.—26. Orion.

1. To all persons in whose minds a taste for the study of nature has been awakened, there is no spectacle which excites an interest so intense as that which is offered by the firmament on a clear night; and to such there is no occupation more pleasing than from season to season to observe on clear nights the changes which take place in that glorious scene. But to render such contemplation still more agreeable, and to enable the intelligent spectator to turn his observations to profitable account, it is necessary that he should render himself familiar with the objects which are there presented in such countless numbers and endless variety.

2. It is a great error to suppose that all useful astronomical observations must necessarily be confined to observatories, and that no one can taste the pleasures offered by practical astronomy who is not supplied with telescopes and other optical and astronomical apparatus. Our Maker has given us, in the eye, an instrument of exquisite structure, and has supplied us with an understanding, by which that organ may be directed to the most sublime speculations. But even when it is useful that the natural limits of our organs of vision may be extended, and their aim directed with greater precision by artificial and scientific aid, much may be accomplished by the most simple and economical means. A common opera-glass will often give us a distinct view of numerous objects which would otherwise escape the naked eye. The most ordinary telescope will be still more useful. And those who occupy themselves habitually with the celestial scenery, so as to be familiarised with its general features, character, and apparent motions, will not be slow to contrive various simple expedients by which the relative position of objects can be ascertained and measured and the succession of their appearances and disappearances anticipated.

We shall therefore, on the present occasion, endeavour to give such plain and simple rules as may enable every one, by the mere use of his eyes, and still more by the occasional use of such optical aids as are almost universally accessible, to occupy himself advantageously with the contemplation of the heavens.

3. Let us then suppose a person totally ignorant of astronomy to stand with his face directed to the south, and to view the heavens on a clear starlight night. No long time will elapse before he will be rendered conscious that the splendid panorama

presented to him is not stationary. In the course of an hour, he will observe that various objects which were visible above the horizon on his right have disappeared; and that, on the contrary, a corresponding number of objects, which were not visible above the horizon on his left, have come into view. By further attention he will perceive that the objects which were at the mid-heavens, in the direction due south, are now no longer so, but have descended towards the right, that is, towards the west, while objects which were to the left of the mid-heavens will have risen to that region.

4. To assist our explanation, let us imagine the entire firmament divided by a line or great circle, rising from the point of the horizon towards which the observer is supposed to look, and being carried vertically upwards to pass over his head, and to descend behind him to the northern point of the horizon. This great line of division, which is called the celestial meridian, divides the whole visible firmament into two equal parts; one lying to the west, or to the right, and the other to the east, or to the left, of the observer.

By continuing his attentive observation of what goes on before him, he will soon perceive that all the objects visible upon the firmament are in motion. That they rise on the east side; that they ascend to the meridian; and then, descending to the west, pass below the horizon and disappear.

5. Let us now suppose our observer to face round and direct his view to the north. A different spectacle will be presented to him. Supposing him to be placed in these climates, he will soon ascertain that the chief part of the objects which are visible in the firmament do not appear and disappear; that is, they do not rise and set. If, for example, any such object be observed upon the celestial meridian over his head so soon after sunset as the stars become visible, he will observe it from hour to hour to descend on his left, that is, towards the west, and to depart more and more from the meridian. So far, however, this is what equally took place when he looked to the south, and had the west upon his right. But after the lapse of a certain time he will find different appearances to be manifested. At the end of about three hours from the time the object referred to began to depart from the meridian, it will be found to have attained a certain limit of distance from the meridian, which will not be exceeded. After this it will begin, on the contrary, again to approach the meridian; but, in doing so, will also approach the horizon, as though it were ultimately destined to set. Such, however, will not be the case; for, at the end of twelve hours, if the return of daylight be sufficiently retarded to enable our observer still to see

the object, it will have returned to the meridian, without having gone below the horizon or disappeared.

In thus passing from an elevated point of the meridian to another point much lower, the object in question will appear to move over a semicircle of the heavens, of which the part of the meridian between the point from which it departed and the point at which it arrives is the diameter.

If the same object could be seen during the succeeding twelve hours, it would be observed to move over the corresponding semicircle to the east of the meridian, that is, to the right of the observer; and, at the end of this second interval of twelve hours, the object would return to that more elevated point of the meridian from which it started.

Such an object, therefore, never rises or sets; and if the presence of the sun did not render it invisible during the day, it might be seen to revolve continually in a circle of the heavens divided into two equal semicircles, east and west, by the meridian, completing its revolution in such circle, and therefore returning to the same point of the meridian, after an interval of about twenty-four hours.

What has been here stated respecting a single object, is true, with certain qualifications, of an immense number of objects visible to an observer looking to the north, as here supposed. All such objects like that described appear to revolve in circles, but not all in the same circle. Some will be found to revolve in greater, and some in lesser, circles; but all such circles are characterised by two most remarkable circumstances, the first of which is, that they all have the same centre, which is a certain point on the celestial meridian; and the second is, that all the objects which move in them, complete their revolution in precisely the same time.

Such being then the general character of the changes which the scene presented by the heavens to the observer undergoes, let us consider some other important circumstances attending it.

6. After attentively contemplating this spectacle for several nights, the observer will not fail to be struck with the fact, that the relative position and configuration of the objects upon it, remains always unchanged. This remarkable circumstance is rendered the more easily observable by the fact that the objects themselves differ greatly in apparent splendour, some being exceedingly bright and conspicuous, while others are barely distinguishable. The observer soon becomes familiar with the relative arrangement and configuration of the brighter and more conspicuous ones; and, grouping them in his imagination, retains their forms so as immediately to recognise them upon their successive reappearances.

7. This circumstance of the unaltered configuration and relative positions of this multitude of objects scattered over the firmament, suggests irresistibly the idea, that the motion of revolution described above, in which they all participate, is not a motion proper to each separate and independent object, but one which belongs to the firmament itself, upon which they appear as if they were fixed. In short, the firmament presents the aspect of a hollow sphere of vast dimensions, in the centre of which the observer is placed, and upon the surface of which the countless multitudes of objects which he beholds are fixed. This stupendous sphere appears to have a motion of revolution on a certain diameter as an axis, making a complete revolution once in twenty-four hours. The diameter round which it revolves, or appears to revolve, is directed to a certain point of the northern quadrant of the meridian, the altitude of which above the horizon of the observer, will be always found to be exactly equal to the latitude of his station. This motion of revolution of the firmament, carrying with it the numerous objects seen upon it, will perfectly explain all the appearances above described, and many others. Thus, it is evident that all objects on the celestial sphere must be moved in circles parallel one to another round its axis; and that these circles become gradually less as the object is nearer to the pole. When the observer looks to the south, the circles described by the objects are partly above and partly below the horizon; and, consequently, all such objects alternately rise and set. But when he looks to the north, the chief part of the objects which he beholds being nearer to the extremity of the axis round which the sphere is carried, describe circles smaller and smaller, which, being entirely above the horizon, the objects in them neither rise nor set.

8. From what has been stated, it will be obvious, that an object placed precisely at that point of the meridian at which the axis round which the sphere turns terminates, would be immoveable; and would evidently be the only immoveable object in the visible firmament. It does so happen, that there actually is no star precisely at that point; but there is a rather conspicuous one so near to it, that although it moves round it in a small circle, the diameter of which is about six times that of the full moon, such motion can only be ascertained by astronomical instruments; and therefore, for all the purposes of common observation, the star in question may be regarded as stationary, and as indicating the position of the northern extremity of the axis on which the celestial sphere appears to revolve.

This point of the sphere is called its *pole;* and as there is a corresponding point at the other extremity of the axis, which is below the horizon, and therefore invisible, it also receives the name pole, and the two points are distinguished,—the visible one as the *North Celestial Pole*, and the invisible one as the *South Celestial Pole*.

The motion of the celestial sphere here described is apparent, not real, being merely an optical illusion produced by the diurnal rotation of the earth upon its axis. But this being a point not immediately connected with our present purpose, it will be sufficient here merely to indicate it. The readers who desire to see the explanation of the apparent diurnal motion of the heavens, will find it in the "Museum," vol. iii. pp. 55, 56.

For all the purposes of the observation of the heavens which for the present occupy our exclusive attention, the celestial sphere is to be considered as revolving on its axis once in about twenty-four hours, carrying with it all the objects seen upon it.

9. The objects scattered over this sphere in such vast numbers, differing one from another greatly in their apparent splendour, and being characterised by very various and often remarkable configurations, astronomers have invented a nomenclature to designate them, founded partly on their relative splendour, and partly on their configurations.

A catalogue of the stars being made, in which each star would hold a place determined by its relative splendour, the more splendid having the higher places; if it were required to resolve such a list into classes, according to their decreasing degrees of brightness, it would be impossible to fix upon any points where each succeeding class would end and the next begin; the gradations of brightness, when star is compared with star, being altogether imperceptible. Nevertheless, a distribution according to degrees of relative splendour being by the common consent of astronomers of all ages deemed expedient, such a conventional classification has been adopted, arbitrary as the limits of the succeeding classes must necessarily have been. In this a certain number of the most splendid stars visible in the firmament have received the denomination of *stars of the first magnitude;* others, of inferior brightness, are called stars of the *second* magnitude, and so on, the smallest stars visible to the naked eye being classed as stars of the *sixth* magnitude.

10. The number of stars of each succeeding magnitude increases rapidly as their splendour diminishes. Thus, while there are no more than 18 or 20 of the first magnitude, there are 50 or 60 of the second, about 200 of the third, and so on; the total number visible to the naked eye, up to the sixth magnitude inclusive, being from 5000 to 6000. We shall see on another occasion that this number, great as it is, is no more than an insignificant fraction

of the total number of stars, the existence of which the telescope discloses to us. But we shall, for the present, limit our observations to the stars which are visible to the naked eye.

It has been stated that the celestial objects generally maintain with relation to each other a certain invariable position, and have no other motion than that imparted to them in common by the sphere to which they are imagined to be attached. To this, however, there is a limited number of exceptions. There is a small number of objects, among which the sun and moon are the most conspicuous, which, while they participate in the diurnal motion of the celestial sphere, are observed continually to shift their position on it, just as if a number of insects were creeping slowly upon the surface of a top while the top is spinning, carrying the insects round with it. These objects, which, exclusive of the sun and moon, are called *Planets*, have occupied our attention on a former, and will again on a future, occasion; for the present, however, we must be understood to notice only those which maintain invariable relative positions, and which have therefore been denominated *fixed stars*.

11. The nomenclature of the stars, so far as it is founded upon their apparent relative positions, consists in the resolution of all the stars of the firmament into a certain limited number of groups, called *Constellations*. These groups have been from ancient times invested with the imaginary forms of men, animals, and various other objects, natural and artificial, and have been named in accordance with these. Thus, the celestial spaces are partitioned out arbitrarily and conventionally into distinct compartments, in a manner somewhat resembling the divisions of the land on the surface of the globe into empires and kingdoms. Each such compartment of the heavens contains a certain number of stars, great and small, the total assemblage of which constitutes the constellation, and is characterised by the proper name conferred upon it.

Since it is of the first necessity that the astronomical student and amateur should be so familiar with this stellar nomenclature as to be able readily to distinguish and recognise not only each principal constellation, but also each principal star in such constellation, we propose here to give such explanations as will present the greatest practicable facilities in the attainment of this object.

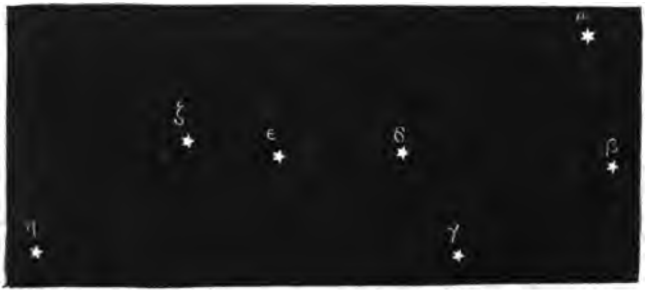
The stars composing each constellation are designated by the letters of the Greek alphabet, the first letters being given to the more splendid stars. When the number of stars in a constellation exceeds the number of letters in the Greek alphabet, the letters of the Roman alphabet are used; and when these are exhausted, the remaining stars, if any, are expressed by the numbers prefixed to them in the catalogue of Flamstead, generally known as the British Catalogue.

It has been customary among English astronomers to designate the constellations by their Latin names; and the astronomical amateur, besides rendering himself familiar with these, will find it convenient, when he is not a Greek scholar, to make himself acquainted with the characters and names of the letters of the Greek alphabet, which are as follows:—

α	Alpha.	ν	Nu.
β	Beta.	ξ	Xi.
γ	Gamma.	ο	Omicron.
δ	Delta.	π	Pi.
ε	Epsilon.	ρ	Rho.
ζ	Zeta.	ς	Sigma.
η	Eta.	τ	Tau.
θ	Theta.	υ	Upsilon.
ι	Iota.	φ	Phi.
κ	Kappa.	χ	Chi.
λ	Lambda.	ψ	Psi.
μ	Mu.	ω	Omega.

12. To obtain an acquaintance with the several constellations and the stars composing them, so as to be able readily to recognise them on viewing the heavens on a clear night, the student should in the first instance study the form and disposition of one of the most conspicuous of the constellations, and the most suitable for this purpose is that which is called *Ursa major*, or the *great Bear*. This constellation is so near the north celestial pole, that in our latitudes it never sets, and is consequently visible at all seasons of the year. It consists of a considerable number of stars, but seven of these, shown in fig. 1, are much more conspicuous than the others, and are consequently the only stars popularly identified

Fig. 1.



with the constellation. They are arranged in such a form, that lines connecting them one with another successively would have the shape of a note of interrogation, or of a reaping-hook.

13. In consequence of the proximity of this constellation to the pole, it never sets in any latitude above that of 40°, and is consequently visible at night in all seasons of the year in the greater part of the northern hemisphere. This circumstance, combined with the splendour of the stars composing it and their remarkable configuration, rendered it an object of universal observation and attention in the earliest ages; and it may therefore be regarded as one of the most ancient of the constellations. It is frequently referred to in the Hebrew Scriptures, and has at various times and in various countries received different denominations. It is referred to, for example, in the book of Job; but the name by which it is designated has been mistranslated in the English version by *Arcturus*, the name of a star in a different constellation. Bochart says that the Hebrew word in Job is derived from an Arabic one which signifies *bier;* others maintain that it signifies a *waggon*, which would be quite consistent with the names given to the constellation by various people, ancient and modern, Greeks, Romans, Italians, Germans, and English, by whom severally it has been named Ἅμαξα (*Amaxa*), waggon or wain; *plaustrum*, cart; *triones*, a waggon and oxen; *feretrum*, bier; *Cataletto*, bier; *Wagen*, waggon; *David's Car*, the *Plough*, and *Charles' Wain.*

14. When the constellation was thus named, the four stars marked α β γ and δ were considered to represent the wheels, and the other three stars the shafts, poles, horses or oxen. When the name *bier* was applied to it, the four stars forming the quadrangle were considered to represent the sarcophagus, and the three remaining stars were considered to represent three mourners, or, according to some, three children of the deceased. Admiral Smyth quotes Kircher as affirming that the four stars of the quadrangle represent the bier of Lazarus, and that the three remaining stars are Mary, Martha, and Magdalen. He also maintains that the popular name of Charles' Wain is a corruption of the Gothic *Karl Wagen*, the churl or peasant's cart.

It is a fact worthy of remark, recorded by historians, that the Iroquois, a tribe of North American Indians were found at the moment of the discovery of America to be familiar with the constellation of the *great Bear*, which in their language was called *Oquoari*, the word which signifies *bear.*

15. Although the only stars of this constellation familiar to the popular eye are the seven principal ones indicated in fig. 1, the group which has received the name of *Ursa major* included from

the earliest times many others of inferior splendour, and this number has been gradually augmented as the range and accuracy of observations have been increased by the improvement of telescopes. From the era of Ptolemy, A.D. 150, to that of Copernicus, A.D. 1500, this constellation contained 35 stars. In the time of Kepler, A.D. 1600, the number was augmented to 56. In Flamstead's Catalogue, A.D. 1700, the number was further augmented to 87, and, in fine, at the beginning of the present century, it was increased to 338.

The constellation, including the stars composing it so far as they are visible without a telescope, is shown in fig. 2, p. 145, where the position and form of the imaginary figure of the bear relatively to the stars are indicated. It will be seen that the four stars α β γ and δ are upon the side, the three others marking the tail.

16. It will be observed in fig. 2 that the principal stars of the constellation, besides being indicated by the Greek letters, are also designated by certain proper names, mostly of Arabic or Oriental origin; and it may here be stated in general that besides the method of designating stars by naming the constellation to which they belong, and the letter which distinguishes them in such constellation, most of the conspicuous stars have received proper names which probably were conferred upon them before the system of constellations was established; and many of these stars are now much more frequently designated by these proper names than by that which connects them with the constellation. Thus, for example, the most splendid star in the constellation of *Canis major* or the *greater Dog*, instead of being called α *Canis majoris*, which would be its name in the nomenclature of the constellations, is almost invariably called *Sirius*. In the same manner, the principal star of the constellation *Leo*, is always called *Regulus* and never α *Leonis*.

These observations, however, are not applicable in the same manner to the seven principal stars of Ursa major, which are more generally designated by the Greek letters which connect them with the constellation.

17. The position of the stars composing a constellation is also frequently indicated by naming the part of the imaginary figure designating the constellation at which the star is found. Thus, for example, the position of η Ursæ majoris, is indicated by stating that it is at the tip of the tail. In like manner, the position of a certain star in the constellation *Taurus*, is indicated by stating that it is in the "bull's eye." This form of expression, which is in very frequent use with astronomers, seems to render it unadvisable to efface altogether from maps of the stars the figures designating the constellations, as is sometimes done.

Although the proper names of the principal stars of Ursa major are not now in general use, they ought not on that account to be altogether overlooked or neglected, since they are often the means of identifying these objects with those indicated in ancient historical records.

Close to the star Mizar, in the tail of the Great Bear, is a small star called *Alcor*, which Humboldt says the Arabs called "saidak," which signifies *trial* or *test*, since they used it as a test of the sharpness of the sight of the observer.

18. If a straight line be imagined to be drawn from the star β to α, and continued beyond α to a distance equal to five times the distance between α and β, or, what is nearly the same, to the whole distance between α and η, it will arrive at the principal star of a smaller constellation called *Ursa minor* or the *lesser Bear*. This is the star already mentioned as being within a degree and a half of the pole, and which, being generally adopted as the easiest practical means of marking that important point, is called the *Pole star*. The other stars of the constellation of Ursa minor have nearly the same configuration as those of Ursa major; but the position of the figure is reversed, the tail, at the tip of which the pole star is placed, corresponding with the head of Ursa major.

The important service thus performed by the stars α and β Ursæ majoris, in indicating by their direction the position of the pole star, has given them the name of the *Pointers;* they are also sometimes called the *Guards.*

This method of ascertaining the position of the principal star and the constellation generally of Ursa minor, by means of the more conspicuous and better known constellation of Ursa major, has been generalised with the greatest benefit to astronomical students and amateurs by extending the method of pointers, so as to trace one constellation from another throughout the entire firmament, as will presently appear.

19. The constellation of Ursa minor being so placed that the principal star, at the tip of the bear's tail, is close to the pole, the diurnal motion of the sphere causes the figure of the bear to swing round the pole feet foremost, as if its tail were nailed to that point. The four successive positions of the constellation at intervals of six hours, are shown in fig. 3, p. 161.

The star β of this constellation, situate on the head of the bear, and therefore more distant from the pole, is easily seen to revolve round the pole as a centre, so that this constellation was regarded as a great celestial clock, and before the advancement of science furnished mariners with other and better means, it was of great use in navigation.

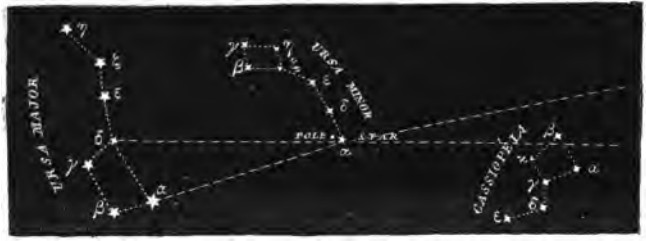
The constellation of the Great Bear being in the quarter of the heavens opposite to that in which the sun is found in the beginning of September, it will be seen on the meridian not far south of the zenith at that season in these latitudes, at midnight.

It will, on the contrary, be on the meridian a little above the horizon at midnight, in the beginning of March. The most favourable times, therefore, for observations upon it, are the months of summer and autumn.

20. A circle described round the north celestial pole, including within it a certain extent of the heavens is called the *Arctic* circle, from the Greek word Ἄρκτος, "arktos," signifying *a bear*, that being, as it were, the region of the bears.

21. To extend the method of pointers to the discovery of the position of other constellations, let us suppose a line carried from the star δ of Ursa major to the pole star, and continued beyond the pole star to an equal distance; this line will then arrive at a well-known constellation called *Cassiopeia's chair*. This constellation consists of several stars, six of which being the most conspicuous are shown in fig. 4. Four of these α, β, κ, and γ, formed the legs and seat, and the two others δ and ε the back.

Fig. 4.

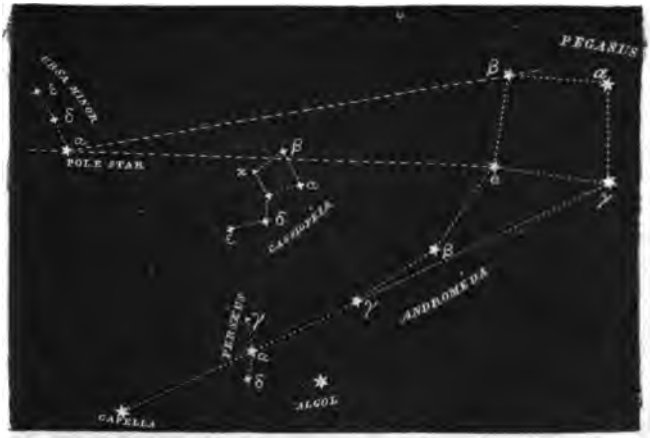


If the line drawn from α of Ursa major through the pole star be continued beyond the latter nearly in a direct line, it will arrive at a constellation called *Pegasus*, which will be easily recognised by four brilliant stars forming a quadrangle very similar to that already described in the constellation of Ursa major. This quadrangle with its position relatively to the pole star, and the line proceeding through that star from the pointers is shown in fig. 5.

22. Of these four stars, three only properly belong to the constellation called *Pegasus;* these three being β, α, and γ, forming the upper right hand corner of the quadrangle. The fourth star, marked also α, belongs to an adjacent constellation called *Andro-*

meda, three of the principal stars of which, marked α, β, and γ, are shown in the figure. By continuing the line of these stars

Fig. 5.



slightly curved, we arrive at another conspicuous star about as far from γ as γ itself is from β. This last is the principal star α of the constellation called Perseus.

23. The seven bright stars, here described, three of which belong to the constellation Pegasus; three others to Andromeda, and the fourth to Perseus, have a configuration strikingly similar to that of the seven principal stars of Ursa major, as will be easily perceived by fig. 4.

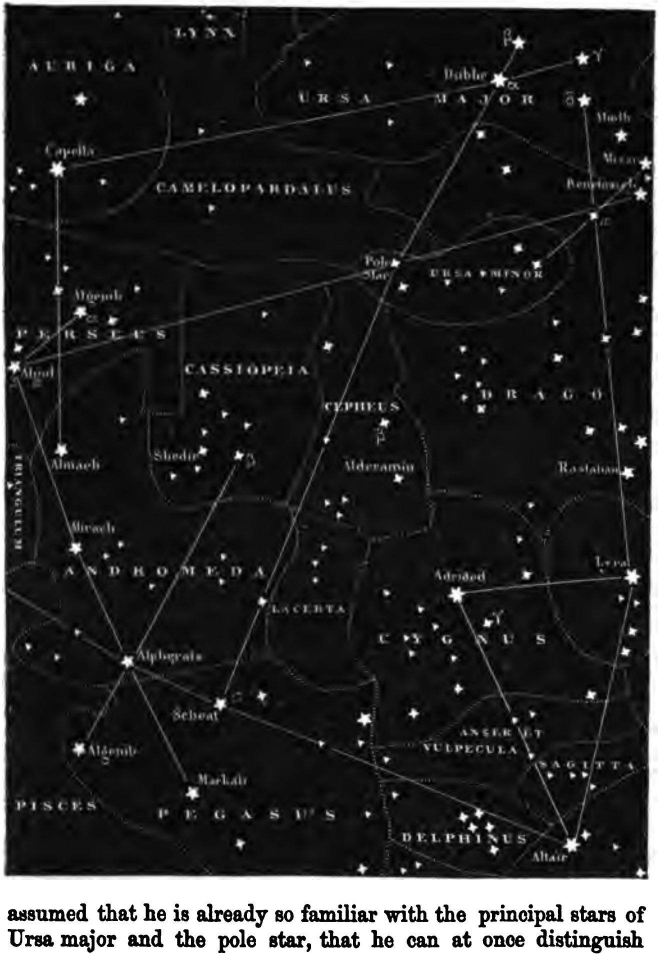
A second bright star, belonging also to the constellation of Perseus, familiarly known in stellar astronomy by the name of *Algol*, is also shown in the figure; it makes a right angle with the other star α of Perseus, and the star γ of Andromeda.

24. If a line be drawn from the star γ of Pegasus, through the star γ of Andromeda, and continued to an equal distance beyond the latter, it will arrive at a splendid star of the first magnitude called *Capella*, being the principal star of the constellation called *Auriga*. This star, and its relative position to the others, is also shown in the figure.

25. A general view of the stars included within the region of the firmament which we have now traced is exhibited in fig. 6, so as to enable the student to perceive at a single view all the stars which have been just indicated. Six of the principal stars of Ursa major appear at the upper right hand angle of the figure,

and lines are drawn in various directions connecting the principal stars, to show the student the manner of tracing the position of those which he seeks, from those which he already knows. It is assumed that he is already so familiar with the principal stars of Ursa major and the pole star, that he can at once distinguish them. Besides the connecting lines already mentioned, he will see that the position of Algol can be ascertained by a straight line drawn from the star η of Ursa major, and continued to nearly an

Fig. 6.

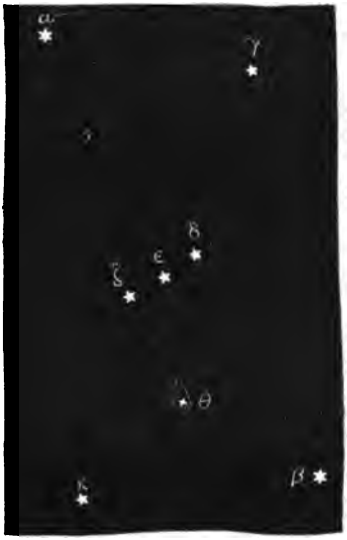


equal distance beyond the pole star. The star Capella can also be found by following the direction of a line through γ and α of Ursa major, as shown in the figure. If a line be imagined to be drawn through γ and δ of Ursa major, and continued onwards to a distance from δ equal to the distance between the pole star and Pegasus, it will arrive at the principal star of the constellation *Lyra*, called *Vega*; and, if a line be drawn from this star at right angles to the former, it will arrive at the principal star of the constellation of *Cygnus*, generally known as *α Cygni*, but also called *Adrided.*

If a line be drawn through the stars α of Andromeda and β of Pegasus, and be continued through the latter to a distance equal to about four times the distance between these stars, it will arrive at another conspicuous star of the first magnitude, shown in the figure, called *Altair*, being the principal star of the constellation *Aquila* or *the Eagle.*

26. The most magnificent constellation of the firmament, surpassing not only in splendour, but in the almost countless number of its component stars, profusely sprinkled also with nebulæ, as will hereafter appear, is Orion, the principal stars of which are shown in fig. 7, and will be immediately recognised by every eye familiar with the appearance of the firmament. This splendid stellar combination, lying across that part of the ecliptic over which the sun passes in December, will always be visible about midnight on the southern meridian in the month of June, and may indeed be viewed with great advantage and facility during the summer and the latter part of spring. The principal stars, when connected by imaginary lines, form a figure resembling that of an hour-glass. The figure from which the constellation takes its name is a mythological personage, celebrated as a giant and a hunter, who after his death was, according to Homer, elevated to the stars (Iliad, lib. xviii. 486; xxii. 29; Od.

Fig. 7.



v. 274,) where he is represented as a giant, with a girdle or belt, a sword, a cloak of lion skin, and a club.

The stars marked α and γ in the figure, are in the shoulders, and those marked κ and β, in the feet. The three central stars, δ ε ζ form the belt.

Manilius, quoted by Admiral Smyth, says of this constellation:—

> "Orion's beams! Orion's beams!
> His star-gemmed belt and shining blade,
> His isles of light, his silvery streams,
> And gloomy gulfs of mystic shade."

No constellation, continues Admiral Smyth, was more noted among the ancients than this. As it occupies an extensive space in the heavens, this circumstance may have probably given Pindar his notion that Orion was of a monstrous size, and hence the "jugula" of Plautus, the "*Magni pars maxima cœli*" of Manilius, and the "jebber" of the Arabians. When the rage for innovation was more prevalent than at present, it was proposed to invest this constellation with the figure and to confer upon it the name of Nelson; and in 1807, when Napoleon was in the meridian of his power, the University of Leipzic passed a resolution that the stars of the belt and sword should be erected into an independent constellation to be called Napoleon.

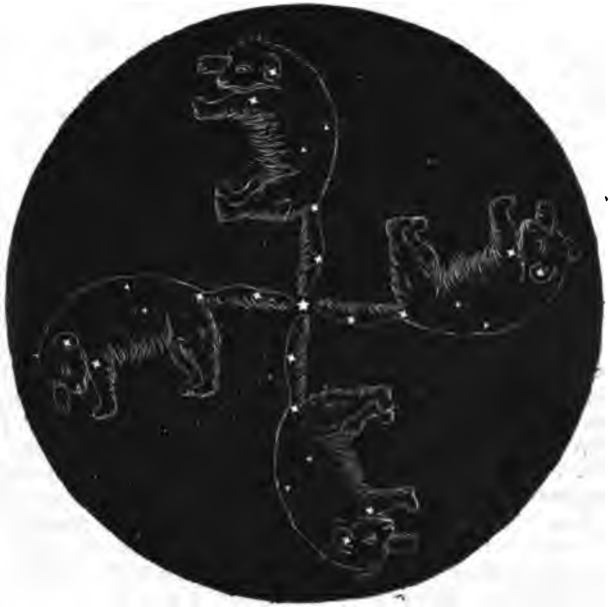


Fig. 3.—THE DIURNAL REVOLUTION OF THE CONSTELLATION OF THE LESSER BEAR.

HOW TO OBSERVE THE HEAVENS.

CHAPTER II.

27. Antiquity of the name of Orion.—28. Nebulæ in the constellation Orion.—29. General view of this region of the heavens.—30. Procyon and Sirius.—31. Aldebaran: the Hyades and the Pleiades.—32. The constellations of the zodiac.—33. Use of celestial maps.—34. Use of a celestial globe.—35. To find the place of an object in the heavens.

27. THE name of Orion is of high antiquity, occurring in the books of Job, Amos, Ezekiel, and Isaiah. Some commentators contend, however, that the personage figured in the constellation is no other than Nimrod. It was believed that when this constellation was in such a position as to precede the sun in rising, storms and rain ensued, and Orion is hence characterised by such epithets as "Imbrifer," (the bringer of rain;) "Nimbosus," (the cloudy;) and "Aquosus," (the watery). The Latin poets overflow

with invectives against the pluviosus et tristis Orion; with Horace, he is the "nautis infestus;" with Propertius, the "aquosus;" and with Pliny, the "horridus sideribus."

Two of the four principal stars, those marked α and β in the figure, are of the first magnitude, the former being generally called by the proper name, *Betelgeux*, and the latter, *Rigel.*

The three stars forming the belt are of the second magnitude, and have been popularly known by different names, such as "Jacob's staff," the "yard wand," and the "three kings."

28. The star marked θ in the figure, situate midway between the three stars of the belt and the two stars of the feet, proves to be a very remarkable object when submitted to examination with adequate telescopic power. It is not one, but five stars, combined in close juxta-position; and is moreover surrounded by one of the most remarkable nebulæ in the firmament. These are points, however, which do not fall within the limits of this Tract, but to which we will return on another occasion.

29. To present to the student a collective view of the conspicuous stars and constellations which have been above described, we have given, in fig. 8, a view of a portion of the firmament within which they are included. If the student imagine himself directing his view to the heavens, with his face to the north, on any night about the middle of June, at or near the hour of midnight, he will see above him the stars and constellations indicated in the upper half of the figure; and, if he turn with his face to the south, he will see those included in the lower half. Immediately above his head, and close to the zenith, he will see the splendid star *Capella;* if he carry his eye from the pole star through Capella, towards the south, he will recognise at once the constellation of Orion, which we have just described. The centre star of the belt will be due south. The bright star Betelgeux will be to the right, and Rigel to the left of the meridian; that is, the former will be west and the latter east of the meridian. If he carry his eye in a direct line from the stars ϵ and δ of Ursa major, he will arrive at the bright star *Pollux* in the constellation *Gemini*, and beside it will see the still brighter star *Castor*, of the same constellation, the latter being of the first, and the former of the second, magnitude.

30. If the same line, directed from the stars of Ursa major through Pollux, be continued nearly in the same direction, it will arrive at *Procyon*, a star of the first magnitude in the constellation of *Canis minor*.

If an equilateral triangle be imagined to be formed upon the south side of the line joining Procyon with Betelgeux, its vertex will fall upon *Sirius*, a star of the first magnitude and the

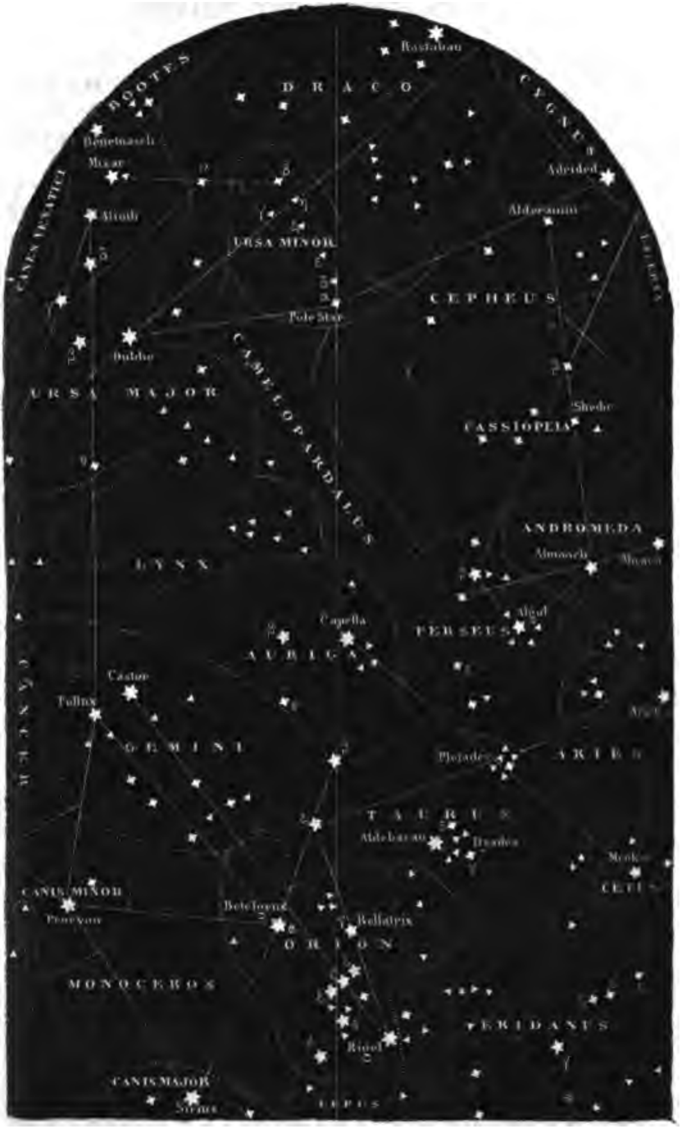


Fig. 8.—GENERAL VIEW OF THE REGION AROUND THE STAR CAPELLA, INCLUDING THE CONSTELLATION OF ORION.

brightest in the firmament, being the principal star of the constellation of *Canis major*, and thence often called the *Dog Star*. Indeed, this star, from its extraordinary splendour, will be recognised at once by the eye, without the necessity of tracing its position by pointers.

31. If a line be imagined to be drawn from Sirius to the star γ, called *Bellatrix*, in the shoulder of Orion, and continued beyond that point to about half the distance between these stars, it will arrive at a conspicuous star of the first magnitude, called *Aldebaran*, in the constellation of Taurus. This star is placed in the southern eye of the bull, and the three stars of Orion's belt may be considered also as pointers to it.

The constellation of Taurus, of which Aldebaran is the principal star, is remarkable for two splendid clusters visible to the naked eye, and which, being known to the ancients, were called the Hyades and the Pleiades; the former group is in immediate juxtaposition with the eye of the bull, and the latter is in its neck. The mythological origin of these constellations is, as commonly given, as follows:—The Hyades were the daughters of Atlas and Pleione, whose brother Hyas being torn to pieces by a bull, they were overwhelmed with grief, and are said to have wept so incessantly, that the gods in compassion took them into heaven and placed them near the bull's eye, where they still continue to weep; and, accordingly, it was a popular superstition that when they rise immediately before the sun, wet weather ensues. Indeed, the name Hyades is derived immediately from a Greek word Ὑάδες, (Hyades), which signifies the "rainers."

The Pleiades, also daughters of Atlas and Pleione, and therefore sisters of the Hyades, were seven in number; six being visible and the seventh invisible. The seventh was called Sterope, and it was related that she became invisible because, while her sisters had all consorted themselves with gods, she alone yielded to Sisyphus, a mortal. According to other traditions, the seventh Pleiad was called Electra, and her disappearance was explained by her grief at the destruction of the house of Dardanus. The Pleiades are said to have destroyed themselves from grief at the death of their sisters the Hyades. They were afterwards placed among the stars, where they formed a cluster resembling a bunch of grapes, whence they were sometimes called Βότρυς (Botrus). The rising of these stars before the sun, like that of the Hyades, was considered to forebode rain.

If the line of the pointers drawn to the pole star be a little deflected to the left and continued onwards, it will arrive at a remarkable star of the first magnitude, shown in the figure, called α *Cygni*, being the principal star in the constellation of Cygnus.

This star is sometimes called *Adrided;* it was called by the Arabians *Deneb.*

32. Every one is familiar with the fact that, in the course of a year, the sun appears to move round a great circle of the heavens called the *Ecliptic,* and in so doing passes through a series of constellations which lie in that route. The stars composing these are generally included within a zone extending to 10° or 12° on each side of the ecliptic. This zone is called the *Zodiac,* from the Greek word Ζώδιον (Zodion), which signifies a small painted or carved figure of an animal, the zodiac being filled with a series of constellations, to which the names and forms of animals were given. The twelve well-known zodiacal constellations are:—

	Sign.		Sign.
1. Aries (the ram)	♈	7. Libra (the balance)	♎
2. Taurus (the bull)	♉	8. Scorpio (the scorpion)	♏
3. Gemini (the twins)	♊	9. Sagittarius (the archer)	♐
4. Cancer (the crab)	♋	10. Capricornus (the goat)	♑
5. Leo (the lion)	♌	11. Aquarius (the waterman)	♒
6. Virgo (the virgin)	♍	12. Pisces (the fishes)	♓

The signs here annexed to the names are abridged means of expressing not the constellations, but the successive divisions of the ecliptic to which the constellation corresponded at the time they received their names. It must here be explained, that by a peculiar change which has taken place in the annual path of the sun through the heavens, that luminary does not now follow precisely the same course which it followed in remote ages. The position of the sun on the day of the equinox is subject to a small change from year to year, which, though insignificant in short intervals of time, becomes very considerable when it accumulates for ages. Thus, when the constellations of the zodiac received their names, the sun entered the constellation Aries on the day of the spring equinox; but, owing to the cause just explained, the moment at which it entered that constellation became from year to year later and later, until, after the lapse of many centuries, it did not enter Aries till a month after the day of the equinox. During the first month after the equinox the sun is therefore at present in the constellation of Pisces, and not in that of Aries.

As there were twelve zodiacal constellations, the ecliptic in which the sun revolves was divided into twelve equal arcs of 30° each, which were called *signs,* the first 30° commencing from its position on the day of the equinox, was called the sign *Aries,* the second *Taurus,* and so on. And although, owing to the change of position of the ecliptic already indicated, the positions of the constellations from which these signs have taken their names have changed so that, in fact, the constellation Pisces is found in the first sign, and Aries in the second, and so on; the signs have, nevertheless, retained their names.

It is therefore important that the astronomical amateur should not confound the name of the *sign* with the name of the constellation. The *sign* Aries is the first 30° of the ecliptic, while the *constellation* Aries is a group of stars, at present situate between the 30th degree and 60th degree of the ecliptic.

The ancients recognised, besides the twelve zodiacal constellations, twenty-one constellations in the northern, and fifteen in the southern hemisphere. The progress of stellar discovery has, however, augmented considerably these somewhat arbitrary groups of stars, and the number of constellations now recognised amounts to 117, of which 62 are in the northern hemisphere.

33. From all that has been explained above, the student will be able to appreciate the benefit to be derived from having in his possession a collection of celestial maps. Many such have been published, among which may be mentioned more particularly those prepared under the superintendence of the Society for the Diffusion of Useful Knowledge. I have found, however, one of the most convenient for general purposes, "The Guide to the Stars." * In the maps there given, will be found indications of the most useful applications of the method of pointing.

34. A celestial globe may be defined to be a working model of the heavens. It is mounted like a common terrestrial globe. The visible hemisphere is bounded by the horizontal circle in which the globe rests. The brass circle at right angles to this, is the celestial meridian. The constellations, with outlines of the imaginary figures from which they take their names, are delineated upon it.

The globe will serve, not merely as an instrument of instruction, but will prove a ready and convenient aid to the amateur in astronomy, superseding the necessity of many calculations which are often discouraging and repulsive, however simple and easy they may be to those who are accustomed to such inquiries. Most of the almanacs contain tables of the principal astronomical phenomena, of the places of the sun and moon, and of the principal planets as well as the times when the most conspicuous stars are on the meridian after sunset. These data, together with a judicious use of the globe and a tolerable telescope, will enable any person to extend his acquaintance with astronomy, and even to become a useful contributor to the common stock of information which is now so fast increasing by the zeal and ability of private observers in so many quarters of the globe.

---

* Twelve Planispheres, forming a Guide to the Stars for every Night in the Year, with an Introduction.—*Taylor and Walton*, London.

To prepare the globe for use, let small marks (bits of paper gummed on will answer the purpose) be placed upon it, to indicate the positions of the sun, moon, and planets, at the time of observing the heavens. The place of the sun on the ecliptic is usually marked on the globe itself. If not, its right ascension (that is, its distance from the vernal equinoxial point, measured on the celestial equator), and its declination (that is, its distance north or south of the equator), are given in the almanac, for every day. The moon's right ascension and declination are likewise given.

35. *To find the place of an object on the globe when its right ascension and declination are known.*—Find the point on the equator where the given right ascension is marked. Turn the globe on its axis till this point be brought under the meridian. Then count off an arc of the meridian (north or south of the equator, according as the declination is given) of a length equal to the given declination, and the point of the globe immediately under the point of the meridian thus found, will be the place of the object. By this rule, the position on the globe of any object of which the right ascension and declination are known, may be immediately found, and a corresponding mark put upon it.

To adjust the globe so as to use it as a guide to the position of objects on the heavens, and as a means of identifying the stars and learning their names, let the lower clamping-screw of the meridian be loosened, and let the north pole of the globe be elevated by moving the brass meridian until the arc of this meridian between the pole and the horizon be equal to the latitude of the place of observation. Let the clamping-screw be then tightened, so as to maintain the meridian in this position. Let the globe be then so placed that the brass meridian shall be directed due north and south, the pole being turned to the north. This being done, the globe will correspond with the heavens so far as relates to the poles, the meridian, and the points of the horizon.

To ascertain the aspect of the firmament at any hour of the night, it is now only necessary to turn the globe upon its axis until the mark indicating the place of the sun shall be under the horizon in the same position as the sun itself actually is at the hour in question. To effect this, let the globe be turned until the mark indicating the position of the sun is brought under the meridian. Observe the hour marked on the point of the equator which is then under the meridian. Add to this hour the hour at which the observation is about to be taken, and turn the globe until the point of the equator on which is marked the hour resulting from this addition is brought under the meridian. The position of the globe will then correspond with that of the firmament. Every object on the one will correspond in its position with its representative mark or symbol on the other. If we imagine a line drawn from the centre of the globe through the mark upon its surface indicating any star, such a line, if continued outside the surface toward the heavens, would be directed to the star itself.

For example, suppose that when the mark of the sun is brought under the meridian, the hour 5h. 40m. is found to be on the equator at the meridian, and it is required to find the aspect of the heavens at half-past ten o'clock in the evening.

	H.	M.
To	5	40
Add	10	30
	16	10

Let the globe be turned until 16h. 10m. is brought under the meridian, and the aspect given by it will be that of the heavens.

VIEW OF GREENWICH OBSERVATORY, SHOWING THE SIGNAL-BALL AT THE TOP OF THE DOME.

LATITUDES AND LONGITUDES.

1. Necessary to know our position on the earth.—2. Poles and equator.—3. Parallel of latitude.—4. Meridian of Greenwich.—5. Latitude and longitude.—6. Methods of determining the latitude.—7. By the sun.—8. By stars.—9. Hadley's sextant.—10. Latitude at sea.—11. To find the longitude.—12. Lunar method.—13. Ball signal at Greenwich.

1. Before it is possible to acquire a distinct knowledge of the position or distances of any bodies in the universe outside the surface of the earth, it is first indispensable that we, who have to make these calculations, should distinctly ascertain our own position in reference to the bodies we observe. But as our position is subject to continual change, as well by reason of the diurnal rotation of the earth upon its axis, on the surface of which we are carried round, as by the annual motion of the globe in its orbit round the sun, we are obliged as a necessary preliminary to analyse with accuracy all the circumstances of these

motions. But even before we are in a condition to accomplish this, there is another preliminary step not less indispensable, which is to ascertain our own position on the surface of the globe we inhabit.

This is not so easy a matter as at the first view it might seem to be. The earth we dwell on is a globe which compared with any familiar standards of measure has a stupendous magnitude. The range of our vision around any situation which we may occupy upon the surface of this globe is small. In the most unobstructed situation we can obtain—that which is presented us at sea, when out of sight of land, on the clearest day—our observation is circumscribed by a radius of a few miles. The portion of the surface which we see at one and the same time, forms in reality so small a patch of the globe of the earth, that it is only by indirect reasoning that we can recognise upon it any character save that of a flat plane. How, then, are we to know in what part of the terrestrial globe that small patch of surface is situated?

2. To answer this question, it is evidently necessary first to settle some fixed points or lines to which we may refer various places, and by which we may express their positions. The points which have been usually selected for this purpose are the POLES and the EQUATOR. The poles are those points on the surface of the earth where the axis on which it performs its diurnal rotation terminates, and they are distinguished, as is well known, by the names of the NORTH and SOUTH poles.

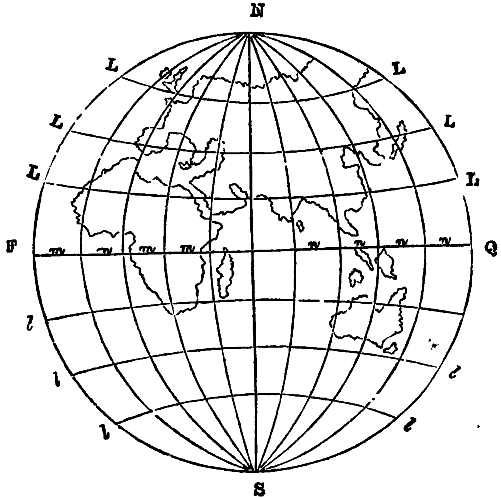
If we imagine a circle drawn round the globe in such a manner as to divide it into two hemispheres, having in the midst of one the north pole, and in the midst of the other the south pole, such a circle is called the EQUATOR, from equally dividing the globe. Every point in this circle will be at the same distance from the poles, and if we imagine the globe to be cut by a plane through the poles, that plane will be at right angles to this circle, and the section it forms will be what is called a TERRESTRIAL MERIDIAN. The arc of this meridian between either pole and the equator will be one quarter of its entire circumference, and will therefore be 90°. The equator is, therefore, everywhere 90° from each of the poles.

In fig. 1, N is the north and S the south pole, and EQ is the equator.

The hemispheres into which the equator divides the earth are called the NORTHERN and SOUTHERN HEMISPHERES. That which includes the north pole, being the northern, and that which includes the south pole, the southern.

The position of a place in either hemisphere with reference to the equator is expressed by stating the number of degrees of a terrestrial meridian included between the place and the equator. This is called the LATITUDE of the place; which is the distance of the place from the equator expressed in degrees of the meridian. Thus, if a place be midway between the pole and the equator, its latitude is 45°. If it be distant from the equator by two-thirds of the entire distance from the equator to the pole, its latitude will be 60°, and so on.

Fig. 1.



3. The latitude is said to be northern and southern, according as the place is in the northern or southern hemisphere.

But it is evident that the latitude alone will be insufficient for the determination of the position of a place. If we state that a certain place is 45° north of the equator, it will be impossible to ascertain certainly the place in question, inasmuch as there is a circle of points on the earth, all of which are 45° north of the equator. If we suppose a circle drawn round the surface of the northern hemisphere parallel to the equator, at the distance from the equator of 45°, every point of such circle will be equally characterised by the latitude of 45° north.

Such a circle is called a PARALLEL OF LATITUDE, and it is therefore apparent that wherever such a parallel may be drawn upon the earth, all the places upon it will have the same latitude.

In the figure E N Q is the northern and E S Q the southern hemisphere. The circles L L, are northern and *l l*, southern parallels of latitude. All places situate upon any one of these circles have the same latitude. The distances of N and S from E Q, being 90° that is the latitude of the poles. The circles N *m* S and N *n* S, drawn upon the earth from pole to pole intersect the equator E Q, and all the parallels L L, *l l*, at right angles. These are TERRESTRIAL meridians.

The latitude is, then, insufficient to determine the position of any place. How, then, it may be asked, can the exact position of any place be expressed?

4. Let us suppose that a meridian is arbitrarily selected, passing through some particular place, such as the Greenwich Observatory. We may conceive another meridian drawn upon the earth east or west of that, so that the two meridians shall include between them an arc of the equator, consisting of a definite number of degrees; say, for example, that it shall consist of 20°; then such a meridian will be defined by stating that it is 20° east or west of the meridian of Greenwich. All that can be settled by such a statement is the position of the meridian in which the place lies with reference to the arbitrarily chosen meridian of Greenwich. This relative position of the two meridians is called the LONGITUDE OF THE PLACE. As the meridian from which the longitude is measured is altogether arbitrary, there being no physical or geographical reason why one meridian should be chosen rather than another, each nation has naturally selected as the zero of longitude the meridian of some noted place in its precincts. In England the Royal Observatory at Greenwich has been the place selected, and accordingly in all English works on geography, political and physical, longitudes are invariably expressed in reference to the meridian of Greenwich. It will, therefore, be most convenient for us here to refer to that meridian.

When these explanations are clearly understood, we shall be in a condition, distinctly and definitely, to express the position of a place upon the surface of the globe of the earth. If we state its latitude and its longitude, we can fix at once, and unequivocally, the position of a place. Thus, let us suppose that its latitude is 50° north, its longitude 30° east of Greenwich; its position will be found by imagining a circle parallel to the equator drawn upon the northern hemisphere at a distance of 50° from the equator; then, supposing a meridian drawn through Greenwich, intersecting this parallel, and another drawn so as to cross the equator at a point 30° east of the former; the place in question will be upon the line parallel to the equator first drawn, inasmuch as it will be 50° north of the equator, and it will be also in the meridian last drawn, inasmuch as it will be 30° east of Greenwich. Since, then, it will be at the same time on both these lines, it will necessarily be at the point where they cross each other at the east of the standard meridian of Greenwich.

5. Thus, then, we have succeeded at least in establishing standards of position and a nomenclature by which the exact position of a place on the surface of the globe can be expressed. But we have still another much more important and difficult question to settle. How are we to discover in what part of the globe any place is which we may occupy at a given time; in other words, how are we to discover its latitude and its longitude? These are questions, especially the latter, attended with some difficulty, and which have been solved by different methods, applicable in different cases, according to the circumstances under which the position of the place is sought, and the purpose for which such position is to be determined.

At any place on land where the geographical position is once determined, it may be recorded, so as to be permanently known for the future without a repetition of the process for determining it; but it is otherwise at sea. On the trackless surface of the deep all marks of events and operations are immediately obliterated, and a new investigation must be instituted in every case when the position of any point is to be determined. The mariner must, therefore, be supplied not only with the means of determining the position of his ship at all times, but with means the application of which is practicable under the peculiar circumstances in which he is placed. The instruments he uses must not only be portable, but must be such as may admit of being manipulated, subject to the disturbances and the vicissitudes of the sea. The objects of his observations must be such as are almost always in his view. It is evident, then, that the problem, as applicable on land, is wholly different in its circumstances and conditions from that which is applied on the deep. But even on land the problem presents itself under various circumstances and conditions. In the fixed observatory, where the observer is supplied with instruments of the greatest magnitude, of the most refined accuracy, and the most absolute stability, methods have been used which are susceptible of the last conceivable degree of accuracy, and accordingly the position of those points on the globe where such observatories have been erected are usually determined with the greatest degree of precision. Such points on the globe serve, therefore, as a sort of landmarks, relative to which the position of all surrounding places may be determined.

The circumstances under which the scientific traveller and geographer makes his observations, with a view to the general determination of the points of a country, are less favourable to accuracy than those available to the astronomer, but still are more susceptible of precision than those which can be placed at the disposal of the mariner. It is, however, the business and the duty of those who devote their lives to the advancement of the sciences, to supply to each class of observers those instruments and methods of inquiry which are capable, respectively of giving results which, in the circumstances of the case, have the greatest attainable accuracy.

TO FIND THE LATITUDE.

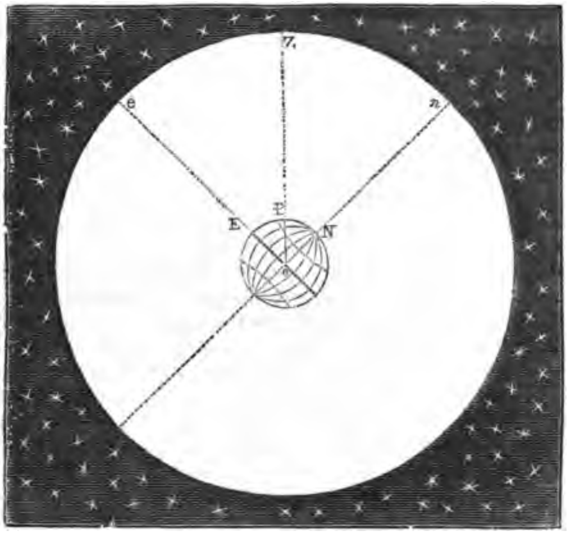
6. Let us suppose the globe of the earth to be represented at O, and let N be its north pole, and E its equator; let P be a place upon it, whose latitude, that is, whose distance from the equator is to be determined. Let *n* Z *e* represent the firmament surrounding the globe at an indefinite distance. The point *n*, immediately over the north pole, and which is in fact the continuation of the line O N, will be the place of the north pole in the heavens, very near to which is a star, called the Polar star. The point *e*, in the continuation of the line O E, will be that which is directly over the equator, and will be that point in the heavens representing the position of the equator; and the point Z, in the continuation of the line O P, the point of the heavens which is directly over the observer at the place P, will be that which is called his zenith. This point is that to which a plumb line would direct itself.

Now the points *n*, Z, and *e* are the points in the firmament which correspond with the points N, P, and E, upon the earth, and it is evident that whatever arcs of the terrestrial meridian N P E are included between these points, similar arcs of the celestial meridian must be included between the points *n* Z *e*. If, then, P E were 40°, Z *e* must also be 40°, just as *n e* is 90°, while N E is also 90°.

In short, the zenith of any place in the heavens is the point in the firmament which corresponds with the position of the place on the globe, and the distance of the zenith in the heavens of one place from the zenith of another, must necessarily be the same in degrees as the distance between two places on earth. Thus Z is the zenith of P; *e* is the zenith of E; Z is the same number of degrees from *e* as P is from E. This being clearly understood, it is evident that if we can, by any means ascertain by observations, the distance from Z to *n*, we can infer at once the distance from P to E, and hence can discover the latitude of the place.

It is apparent, then, if we can observe the distance of the zenith of any place from the celestial pole, that will give us the distance in degrees of the place itself from the terrestrial pole, and by subtracting that from 90°, we shall obtain the distance of the place itself from the equator, or what is the same, its latitude. As an example of this, let us suppose that in measuring the distance from Z to *n* we find it to be 50°, we infer, therefore, that since the distance of the zenith from the pole is 50°, the distance of the place from the terrestrial pole is also 50°.

Fig. 2.



But since the terrestrial pole is 90° from the equator, it follows that the distance of the place from the equator must be 40°, and it is north or south, according as the zenith of the place is in the northern or southern hemsiphere of the firmament.

Thus, then, it appears that the latitude of a place can always be found, provided we can measure the distance of its zenith from the celestial pole; and this, of course, can always be done by the use of proper instruments, provided that the zenith and the pole can be distinctly seen. Now the direction of the zenith can always be determined by the plumb line; but although the pole star is very near the pole, it is not exactly at it; there is, in fact, no star exactly at the pole, and there being no visible object there, it is impossible to measure directly its distance from the zenith. This difficulty is eluded by measuring the distance of the zenith from some star, or other celestial object, whose distance from the pole happens to be known: for example, suppose that there were a star directly between the zenith and pole, whose distance from the pole was known to be 10°. Then if we find the distance of the zenith from this star to be 40°, we should immediately infer the distance of the zenith from the pole to be 50°.

It is in fact, then, by this device that the latitude is always ascertained. By various observations made by astronomers, the positions of most of the stars and other celestial objects, with respect to the poles, are known and recorded; and when we desire to determine the latitude of any place, we measure the distance of the zenith of that place from some celestial object whose position with respect to the pole is known, and thence infer the position of the place with respect to the terrestrial pole; and from that deduce at once the latitude.

7. But our purpose would be equally served if we were supplied with the position of any visible object with reference to the celestial equator. Thus, if we know the distance of the centre ot the sun from the celestial equator, we shall readily be able to find the latitude; for it would only be necessary when the sun is in or very near the meridian, that is, at or near noon, to measure the distance of the zenith of the place from the centre of the sun. This would be done by measuring the distance of the zenith, first from the upper, and then from the lower limb of the sun. The distance from the centre would be the mean between these.

Let us suppose, for example, that the sun being between the zenith and the equator, we find that the distance from the zenith to the centre of the sun is 20°, and that we also ascertain from the table of the position of the sun, that the distance of the centre of the sun at that time from the equator, is also 20°, we should infer at once that the distance of the zenith from the equator must be 40°, and that such, therefore, must be the latitude of the place.

This method of ascertaining the latitude is, perhaps, the most easily practicable. The observations may be performed daily, at noon, when the sun is visible: and in all almanacs, the distance of the centre of the sun from the equator, which is called the sun's declination, is registered. The instrument by which the observations are executed on land is, usually, a quadrant furnished with a telescope moving upon its centre. One radius of the quadrant is placed in the direction of the plumb line, and therefore points to the zenith. The telescope moves round the centre until it is directed to the object whose distance from the zenith is to be observed. The angle between the telescope and the vertical radius of the quadrant will then be the same as the distance of the object from the zenith.

8. In astronomical observatories methods of observation have been applied susceptible of much greater accuracy. Stars upon the meridian can there be used with great advantage. The distances of these stars from the pole are accurately known, and the astronomer selects for his observation those conspicuous stars which pass near to his zenith. He observes the arc of the celestial meridian between his zenith and these stars. And from the magnitude of the arc and the distance of the star of the celestial pole, he discovers the distance of the zenith from the pole and thence the latitude.

The principal source of accuracy in this method is, that the distance between the zenith and the star being very small, is capable of more exact measurement, for reasons connected with the structure of the astronomical instrument, than could be attained in the measurement of greater angles.

9. In observations made at sea, it is not practicable, however, to use the plumb line, and indeed, even for the purposes of geographers it is not always convenient. An admirable instrument has been invented equally applicable to observations by land or by water, called Hadley's sextant, by means of which the observations can be made with reference to the horizon, independent of the zenith, and therefore independent of the plumb line.

It is not our purpose here to enter into a description of the principles and structure of this celebrated and most useful instrument. It will be sufficient for the present purpose to state that it is capable of being applied to the measurement of the angular distances between any two visible objects with a very great degree of precision, and that it may be used with facility, even when the position of the observer is subject to all the unsteadiness incidental to the condition of the mariner.

When this instrument is used, instead of observing the distance of any object from the zenith, we observe its distance from the horizon, which will answer the same purpose, inasmuch as that whenever the distance of an object from the horizon is known, its distance from the zenith can be found, since the distance from the zenith to the horizon being 90°, if we subtract the distance of the object from that, the remainder will be the distance of the object from the zenith.

At sea we have generally, indeed almost always, a well-defined horizon. If the mariner desires to measure the altitude of an object, he has only to measure the distance of the object from the horizon in a direction perpendicular to it, and this he is enabled to do with a little practice, with admirable facility and precision, with Hadley's sextant.

10. Let us see, then, how the mariner is thus enabled daily to determine the latitude of his ship.

As noon approaches, the sky being sufficiently clear to render the disc of the sun visible, he applies the instrument and finds the altitude of the lower limb which he continues to observe until it ceases to increase. He then adds to it the apparent semi-diameter of the sun which is given by the tables, and thus obtains the altitude of the sun's centre. If this altitude be taken from 90°, the remainder will be the distance of the sun's centre from the zenith. He finds in his almanac the distance of the centre of the sun on that day from the equator, and hence he at once, as already explained, obtains the distance of his zenith from the equator; that is the latitude of the ship.

There are several minute circumstances observed in the practice of this problem, which do not affect its general spirit, and the introduction of which here would be unsuitable to our object; we therefore omit them.

Thus we see that, whether by sea or by land—whether in the observatory of the astronomer, traversing the sands of the desert or the forests of America, or voyaging over the trackless and unimpressible surface of the ocean—we are in every case by science supplied with suitable and practicable means by which we can ascertain the distance of the place where we are, north or south, on the globe.

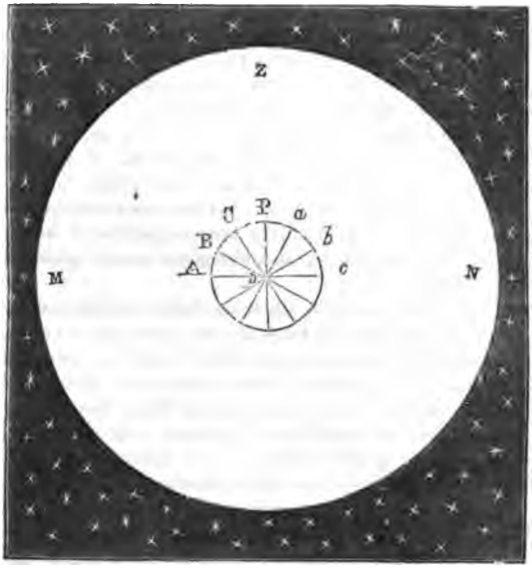
TO DETERMINE THE LONGITUDE.

11. In expressing and determining the latitude of a place, we have fixed points and lines on the firmament to refer to—such as the celestial pole and equator; and to find it, nothing more is necessary than to ascertain the position of the zenith of the place with reference to these. But with respect to the longitude, the case is very different; it is impossible even to express the longitude without involving a reference to two places at least—that of which we wish to determine the longitude, and that which is selected as the starting point from which all longitudes are to be measured. If we could observe in the firmament the two points which at the same time form the zeniths of the two places, then the difference of their longitudes could be found by

noting the times at which these two points would cross the meridian of the place whose longitude is to be determined.

To comprehend fully the spirit of the celebrated problem of finding the longitude, we must imagine the globe of the earth turning on its axis, having around it the starry firmament. Let us suppose A B C, *a b c*, to be the parallel of latitude of the place P, whose longitude is to be determined, *p* being the pole, and let M Z N represent the firmament. Let the zenith be the point on the firmament marked by Z. If we suppose the globe to turn upon its axis in the direction of A B C, *a b c*, the place P will, by its rotation be carried to the right of Z, and the same point Z will become successively the zenith of the points C B and A; and, in fact, every point in the parallel of latitude will successively come under the point Z, which will be, therefore, in regular succession, their zenith points. In twenty-four hours, or, more accurately, in twenty-three hours and fifty-six minutes, the globe will make its complete revolution; therefore three hundred and sixty degrees of the parallel will successively pass under the same point of the firmament.

Fig. 8.



By knowing exactly the time of rotation of the earth, and having ascertained that its diurnal motion is uniform, we can determine by simple arithmetic what extent of its surface will pass, in a given time, under any point of the firmament. Thus if we say in round numbers that the whole circumference corresponds to twenty-four hours, it will follow that fifteen degrees will move under the point Z each hour, or one degree in four minutes.

If we suppose Z to represent the place of the sun, then it will be noon, or twelve o'clock, at the place which is immediately under Z; that is, at P. If C be fifteen degrees west of P, then it will arrive under Z one hour after P; consequently, when it is noon at P it is eleven o'clock at a place fifteen degrees to the west of P; and, for the same reason, it is ten o'clock at a place thirty degrees to the west of P, and so on.

Again: if *a* be a place fifteen degrees to the east of P, *a* must have been under Z an hour before P reached it. It will be noon, therefore, at *a*, an hour before it is noon at P; therefore, when it is noon at P it is one o'clock at *a*. In the same manner, and for like reasons, if *b* be a place thirty degrees east of P, *b* will pass under Z two hours before P; and therefore when P passes under Z it will be two o'clock at *b*.

It will be apparent from these explanations, that in general, the hour of the day at different places upon the earth, at the same time, will depend upon their relative position east or west of each other. If one place be east of another, the hour at that place will be later with respect to noon than the hour at the other; and the extent to which it is later will depend on the distance which one place is east of the other. In calculating this difference of time from the difference of position east or west, we may take fifteen degrees to correspond with an hour, as already explained.

But this distance of one place east or west of another, expressed in degrees, is, in fact, the difference of their longitudes; and if one of the two places in question be that from which the longitudes are measured, the determination of the longitude of a place would resolve itself into the discovery of the hour of the day in the place whose longitude we want to find, and also at the place from which the longitudes are measured.

Thus, for example, let us suppose that we ascertain the hour of the day in New York, and find that it is two o'clock in the afternoon, and that we have a means by which we can discover, at the same time, what the hour of the day is at Greenwich, and that by these means we know that it is 56 minutes past 6 o'clock. We know, then, that the time is 4 hours 56 minutes earlier at

New York than at Greenwich, and consequently we infer that New York must be west of Greenwich by a longitude which corresponds to 4 hours 56 minutes. Now 4 hours correspond to 60°, and 56 minutes correspond to 14°; therefore it follows, that the longitude of New York must be 74° west of Greenwich. We can, then, always discover the longitude of any place, provided we can ascertain, at any moment, the hour of the day at the place in question, and know, at the same time, what the hour of the day is in that place from which the longitude is measured.*

There are simple methods of observation and calculation by which the hour of the day in the place where we are can be determined, with more or less accuracy, according to the circumstances of our position. If we are on land, and supplied with a proper transit instrument, we can, by its means, observe the moment at which the centre of the sun's disc passes the meridian. Thus, as the moment of noon arrives, by observing it, we can set a good clock, which will inform us of every other hour of the day. But even in the absence of a clock, we can determine the hour of the day at any moment at which the sun is visible, by observing its altitude, having previously ascertained the latitude of the place at which we are.

If we are at sea, where we cannot command a transit instrument, nor use it if we could, the latitude of the place of the ship is first determined, and then the hour is found by observing the altitude of the sun at any convenient time in the afternoon or forenoon. The hour being once found, the time can be kept by a chronometer for any number of hours afterward. Thus it appears, under all circumstances, whether at sea or on land, there is no practical difficulty in determining what o'clock it is where we are. This at once reduces the problem of the longitude to the simple discovery of the hour of the day, at any given time, at the place from which the longitudes are reckoned.

The first and most obvious method of accomplishing this which would occur to the mind, would be to carry a good chronometer from the place from which the longitude is reckoned. Supposing this chronometer subject to no error, it will continue to inform you of the hour of the day at that place. Thus, suppose that on leaving London the mariner takes with him a chronometer set according to the time at Greenwich, and with it makes his voyage to New York; the chronometer will continue to inform him what the time is from hour to hour at Greenwich. When he arrives at New York, he will find that when the chronometer points to 12 o'clock, or noon, it will be early in the morning; and if he ascertains the hour exactly, he will find that it will be 4 minutes after 7 o'clock. He will therefore know that the time at New York is 4 hours 56 minutes earlier than at Greenwich, and, consequently, that New York must be 74° west of Greenwich. It is for these reasons that the perfection of chronometers has always been considered so essential to the progress of navigation. Every ship that makes a long voyage ought to be supplied with one, at least, of these instruments; but as they are liable to accident, and as even the best of them cannot be rendered perfect, it is usual with ships that are well provided for long voyages to carry more than one chronometer.

---

* There are several corrections to be attended to in the practical working of the methods of determining latitude and longitude which we have purposely omitted, as they do not affect the spirit of the method, which is all we would here convey.

Although the art of constructing time-keepers has been brought to a high degree of perfection by the skill of modern artisans, these instruments are even yet, and probably will ever continue to be, too imperfect to be implicitly and exclusively relied upon. If we only required their indications for short spaces of time, such as a few days, or even weeks, we might perhaps place a secure reliance upon them; especially if the voyager were provided with more than one instrument of this kind. But in voyages or journeys which occupy months, we cannot rely on the indications of these instruments, even when most liberally provided and most perfectly constructed.

In the absence, then, of a chronometer, how, it will be asked, can the longitude of a place be ascertained at all? The first method that will occur to the mind, will be that of some conspicuous signal which can be seen at the same time at the two places, whose difference of longitude is to be determined. For this we require two observers; but it is perhaps the method of all others susceptible of the greatest accuracy. Let us suppose that on some elevated position, between two distant places, such as London and Birmingham, a conspicuous light is produced, such as the celebrated electric light, which might be exhibited on the top of a high mountain so as to be visible at once from both places. Let this signal light be suddenly extinguished, and let the observers stationed at London and Birmingham note the exact moment at which this extinction takes place. By comparing afterwards these times the exact difference of longitude of the two places will be found.

12. But this method is evidently applicable only on a limited scale, and under peculiar circumstances; it is altogether unavailable to the mariner. Now the astronomer supplies him with a chronometer of unerring precision; a chronometer which can

never go down, nor fall into disrepair; a chronometer which is exempt from the accidents of the deep; which is undisturbed by the agitation of the vessel; which will at all times be present and available to him wherever he may wander over the trackless and unexplored regions of the ocean. Such a chronometer has been found; made by an Artisan who cannot err, and into whose works imperfection can never enter. Such a chronometer is supplied by the firmament itself. The unwearied labours of modern astronomers have converted the face of the heavens into a clock, and have taught the mariner to read its complicated but infallible indications. We may regard for this purpose the firmament as the dial-plate of a chronometer on an immense scale. The constellations and the fixed stars upon it, which, for countless ages, are subject to no change in position, serve as the hour and minute-marks. The sun, the moon, and the planets, which move continually over the surface of this splendid piece of mechanism, play the parts of the hands of the clock. The positions of these bodies from day to day and from hour to hour, and every change of their positions, are accurately foreknown and exactly registered in a book published some two or three years in advance, called the "Nautical Almanac," and circulated for the benefit of mariners. In this work the navigator is told what the hour is or will be at Greenwich for every variety of position which the sun, moon, and planets shall have from time to time upon the heavens. But of all objects in the heavens, that which is best suited for this species of observation is the moon, and hence this method of determining the longitude at sea has been distinguished by the appellation of the *lunar method.* By the use of Hadley's sextant, which we have already alluded to, it is easy, whenever the heavens are clear, to observe the angular distance of the moon either from the sun or from the most conspicuous stars or planets. The motion of the moon in the firmament is so rapid that its change of position is perceptible, even by such observations as can be made on board a ship from hour to hour.

How, then, it may be asked, can such observations be made subservient to the discovery of the longitude of a ship? Nothing can be more simple. The navigator requires only to know what is the hour at Greenwich at the time he makes his observation. This he discovers in the following manner: He observes with the sextant the distance of the moon from the sun, or from some of the most conspicuous stars; he then, after certain preliminary calculations not necessary to detail here, examines the "Nautical Almanac," where he learns what the hour is at Greenwich, when it has these particular distances from the sun or the stars. Knowing this, and knowing the hour where he is, the difference of the longitude of a ship and the observatory at Greenwich is known to him.

13. To supply ships leaving the Thames on long voyages with the exact Greenwich time, the following expedient is adopted:

The Royal Observatory, built on an elevated ridge, forms a conspicuous object from the river. It was, therefore, decided that a signal should be given at the instant of one o'clock in the afternoon of each day; by observing which, navigators within view of the observatory could correct their chronometers. The signal adopted for this purpose was the sudden fall of a large black ball, placed upon a pole raised from the top of one of the towers of the observatory.

Before elevating the ball, at five minutes before one o'clock, a signal is made of the intention to do so by raising it half-mast high. Observers are then instructed to prepare their chronometers; and as the descent of the ball occupies several seconds, they should confine their attention to observing the moment when the ball leaves the top, as it is that alone which indicates the hour.

The use of this signal is not merely confined to the indication of the mean time at Greenwich for navigators going down the river. By observing the drop of the ball, repeated day after day, mariners who are in the river will be enabled to ascertain the daily rate of their chronometers.

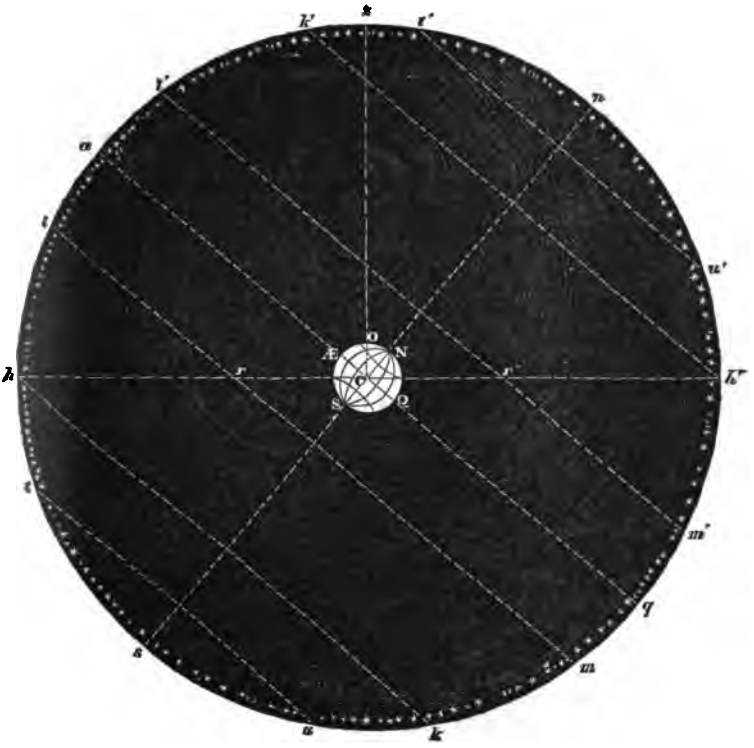


Fig. 2.

COMMON THINGS.

THE EARTH.

1. Difficulty of observing the earth as a whole.—2. It appears at first an indefinite flat surface.—3. This disproved by travelling round it.—4. Proof of the curvature of its surface by observation of distant objects at sea.—5. By the Earth's shadow projected on the Moon.—6. Inequalities of surface, such as mountains and valleys, insignificant.—7. Magnitude of Earth, how ascertained.—8. Length of a degree of latitude.—9-10. Illustrations of the Earth's magnitude.—11. Is the Earth at rest?—12. Apparent motion of the firmament.—13. Origin of the word "Universe."—14. This apparent motion may not be real—may arise from the rotation of the Earth.—15. How such a rotation would produce it.—16. Poles.—17. Equator.—18. Hemispheres.—19.

Meridians.—20. Which of the two rotations is the more probable?—21. Rotation of the universe impossible.—22. Simplicity of the supposed rotation of the globe.—23. Direct proofs of this motion.—24. Foucault's experiment.—25. Its analogy to the planets.—26. Conclusion as to the globular form of the earth requires modification.—27. All human knowledge tentative and approximative.—28. Rotation not compatible with the exact globular form.—29. Centrifugal force of the Earth's rotation.—30. The globe rotating would assume the form of an oblate spheroid.—31. The degree of ellipticity would vary with the velocity of rotation.—32. Experimental illustration.—33. Ellipticity corresponding to the diurnal rotation.—34. How these circumstances affect the actual state of the Earth.—35. Form of a terrestrial meridian.—36. Dimensions of the terrestrial spheroid.—37. Its departure from an exact globe very small.—38. Its density and mass.—39. Determined by Cavendish and Maskelyne.—40. Its total weight.

1. LOCKE somewhere observes, with his usual felicity of illustration, that the "mind, like the eye, while it makes us see and perceive all other things, can never turn its view with advantage upon itself." We encounter something similar to this in our researches through the universe; for of all the objects which compose it, one of the most difficult of which to obtain a complete and accurate knowledge is the planet which we inhabit. The cause of this is our proximity to it, and intimate connexion with it. We are confined upon its surface, from which we cannot separate ourselves. We cannot obtain a bird's-eye view of it, nor at any one time behold more than an insignificant portion of its surface. We have the same difficulty in obtaining an acquaintance with it that a microscopic animalcule would have in acquiring a perfect knowledge of the form and dimensions of a terrestrial globe twelve inches in diameter, on the surface of which it creeps.

Still, by a variety of indirect methods supplied by the ingenuity of scientific research, we have been enabled to ascertain its form, dimensions, and physical constitution, with a considerable degree of accuracy.

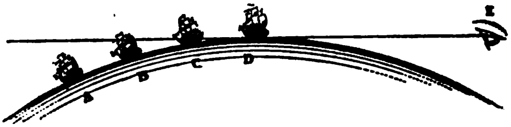
2. The first impression produced upon the eye of an observer, who has not carried his inquiries further, is, that the surface of the earth is a flat plane, interrupted only by the inequalities of the land. A little careful observation, however, upon the many phenomena which are easily accessible to every observer, will correct this erroneous impression.

3. It is well known that if a voyage were made upon the earth, continually preserving one and the same direction, or doing so as nearly as circumstances will permit, we should at length arrive at the place from which we departed. If the earth were an indefinite plane, this could not happen. It is evident, then, that whatever be the exact form of the earth, it is a body which is on

every side limited, and one which must therefore have such a surface that a traveller or navigator can completely surround it in one continuous course.

4. Let us see, however, whether we may not obtain evidence more distinct as to its form. If we stand on the deck of a ship at sea, and out of sight of land, the view being bounded only by sea and sky, and look at the horizon when a ship (A, fig. 1) approaches, we shall at first see its topmast rising out of the water like a pole.

Fig. 1.



As it gradually comes nearer to us (as at B), more of the mast will become visible, and the sails will be seen—cut off, however, horizontally, by the line at which the water and sky unite. Upon the nearer approach of the ship (as at C and D), the hull will at length become visible. Now since this takes place on all sides around us, it will follow that when the ship is at a distance, there must be *something* interposed between the eye and it which intercepts the view of it; but as the surface of the water is generally uniform, and not subject to sudden and occasional inequalities like that of the land, we can only imagine its general form to be convex, and that its convexity is interposed between the eye and the object so as to intercept the view.

Since the same effects are observed from whatever direction the ship may approach, it will follow that the same convexity must prevail on every side.

If, on the contrary, the surface extending from the eye to the ship were a plane, the ship would be rendered invisible only by reason of its distance; whereas it is ascertained that a ship frequently is invisible at a distance at which it must be seen but for the interposition of some other object; this may be tested, and in fact is frequently tested at sea by mounting to the masthead, whence the seaman being enabled to overlook the convexity, sees vessels which are invisible from the deck, although, strictly speaking, he is nearer to those vessels on the deck than at the masthead.

When the mariner, after completing a long voyage, discovers by his observations and reckonings that he is approaching the desired coast, he ascends to the topmast and looks out for the appearance of mountains or other elevated land, and he invariably sees them from that point long before they are visible from the deck. He afterwards sees them from the deck long before the general level of the country will be observed by him. All these are natural and necessary consequences of the convexity of the surface of the ocean. The same effects would be seen in any part of a continent which is sufficiently free from mountains and other inequalities.

5. But we have a still more conclusive and convincing proof of the general form of the earth even than those which have been explained. When the moon passes directly behind the earth, so that the shadow which the earth projects behind it in the direction opposite to the sun shall fall upon the moon, we invariably find that shadow to be, not as is commonly said, circular, but such exactly as one globe would project upon the surface of another globe. Now, as this takes place always, in whatever position the earth may be, and while the earth is revolving rapidly with its diurnal motion upon its axis, it follows that the earth must either be an exact globe or so little different from a globe that its deviation from that figure is undiscoverable in its shadow.

We may, then, consider it demonstrated that the earth may be practically regarded as globular in its form. We shall hereafter see that it slightly departs from the spherical figure, but our present purpose will be best answered by regarding it as a globe.

6. The objection will doubtless occur to many minds that the inequality which exists on the surface of that portion of the globe that is covered by land, especially the loftier ridges of mountains, such as the Andes, the Alps, the Himalaya, and others, are incompatible with the idea of a globular figure. If the term globular figure were used in the strictest geometrical sense, this objection doubtlessly would have great force. But let us see the real extent of this presumed deviation from the globular form. The highest mountain on the surface of the globe does not exceed five miles above the general level of the sea. The entire diameter of the globe, as we shall presently see, is eight thousand miles. The proportion, then, which the highest summit of the loftiest mountains bears to the entire diameter of the globe will be that of five to eight thousand, or one to sixteen hundred. If we take an ordinary terrestrial globe of sixteen inches in diameter, each inch upon the globe will correspond to five hundred miles upon the earth, and the sixteen hundredth part of its diameter, or the hundredth part of an inch, will correspond to five miles. If, then, we take a narrow strip of paper, so thin that it would take one hundred leaves to make an inch in thickness, and paste such a strip on the surface of the globe, the thickness of the strip would represent upon the sixteen-inch globe the height of the loftiest mountain on the earth. We are then to consider that the highest

mountain-ranges on the earth deprive it of its globular figure only in the same degree and to the same extent as a sixteen-inch globe would be deprived of its globular figure by a strip of paper pasted upon it the hundredth part of an inch thick.

It is supposed that the greatest depth of the ocean which covers any portion of the globe does not exceed the greatest height of the mountains upon the land. If this be true, the ocean upon the earth might be represented by a film of liquid laid with a camel's hair pencil upon the surface of a sixteen-inch globe.

It is apparent, therefore, that depths and heights which appear to the common observer to be stupendous, are nothing when considered with reference to the magnitude of the earth; and that, so far as they are concerned, we may practically regard the earth as a true globe.

7. Having ascertained satisfactorily the form of the earth, our next enquiry must be as to its magnitude; and since it is a globe, all that we are required to know is the length of its diameter.

If a line were described surrounding the globe, so as to form a circle upon it, the centre of which should be at the centre of the globe, such a circle is called a *great circle* of the earth. Now if we know the length of the circumference of such a circle, we could easily calculate the length of its diameter, for the proportion of the circumference to the diameter is exactly known. But we could calculate the circumference if we knew the length of one degree upon it, since we know that the circumference consists of three hundred and sixty degrees; we should therefore only have to multiply the length of one degree by three hundred and sixty to obtain the circumference, and should thence calculate the diameter.

8. In our tract upon latitudes and longitudes, it was shown how the latitude of a place can be ascertained. Now, let us suppose two places selected which are upon the same meridian of the earth, and therefore have the same longitude, and which are not very far removed from each other. Let them, moreover, be selected so that the distance between them can be easily and accurately measured. Now let the latitude of these two places be exactly determined, and let us suppose for example that the difference between these two latitudes is found to be one degree and a half; and supposing also that on measuring the distance between them, that distance is found to be one hundred and four miles and thirty-five hundredths. We should thence infer that such must be the length of one degree and a half of the earth's surface, and that consequently the length of one degree would be two thirds of this, or sixty-nine and a half miles. Having thus found the length of

a degree, we should have to multiply it by three hundred and sixty, by which we should obtain the circumference of the earth. This would give twenty-five thousand and twenty miles, and we should then find by the usual mode of calculation the diameter of the earth, which would prove to be a little under eight thousand miles.

The fact that a degree of the earth's circumference consists in round numbers of just so many thousand feet as there are days in the year, supplies a very convenient aid to the memory.

We have made these calculations chiefly with a view of rendering the principles of the investigation intelligible. The more exact dimensions of the earth will be explained hereafter.

We conclude, then, that the earth is a globe eight thousand miles in diameter.

9. To enounce this stupendous arithmetical result is much easier than to obtain any distinct notion of the actual magnitude which it expresses. Such a globe has a circumference of twenty-five thousand miles. A locomotive engine travelling incessantly night and day, at twenty-five miles an hour, would take about forty-two days to go round it.

10. When the diameter of a globe is known, its surface and volume or cubical bulk can be easily determined. To find the surface we have only to take three hundred and fourteen hundredths of the square of the diameter, and to find the volume, five hundred and twenty-four thousandths of the cube of the diameter. In this way we find that the surface of the earth measures two hundred millions of square miles, and that its cubical bulk is about two hundred and sixty thousand millions of cubic miles.

If the materials which form such a globe were built up in the form of a vertical column, the base of which would have the magnitude of England and Wales, its height would be nearly four and a half millions of miles!

11. Such being the dimensions of the globe we inhabit, we are next to consider what is its condition as to motion. Is it, as it appears, at rest? For several thousand years in the history of the human race, it was not only so considered, but he that would have ventured to call in question its stability and quiescence would have been deemed insane. Certain expressions in the sacred Scriptures being erroneously supposed to affirm its immobility, it was deemed heretical to deny it; and Galileo, who did so, was put to the torture by the ecclesiastical authorities of the day, and compelled to admit its quiescence. This verbal admission was, however, so utterly opposed to his convictions, that, on quitting the presence of the inquisitors, he stamped on the ground, and muttered the words, "It moves for all that."

12. A few hours' attentive contemplation of the firmament at night will enable any common observer to perceive, that although the stars are, relatively to each other, fixed, the hemisphere, *as a whole*, is in motion. Looking at the zenith, that is the point directly above our head, constellation after constellation will appear to pass across it, having risen in an oblique direction from the horizon at one side, and, after passing the zenith, descending on the other side to the horizon, in a direction similarly oblique. Still more careful and longer continued observation, and a comparison, so far as can be made by the eye, of the different directions successively assumed by the same object, creates a suspicion, which every additional observation strengthens, that the celestial vault has a motion of slow and uniform rotation round a certain diameter as an axis, carrying with it all the objects visible upon it, without in the least deranging their relative positions or disturbing their arrangement.

When these loose impressions of the senses are submitted to the more exact means of observation which are at the disposition of astronomers, it is found that all the appearances of the heavens, the rising and the setting of the stars, the sun and the moon, their apparent motion in ascending to, passing, and descending from, their several points of culmination, is that of a sphere revolving with an uniform motion round the diameter which is directed to the pole.

The world we inhabit therefore would, to judge from these phenomena, seem to be fixed in the centre of a hollow sphere of vast magnitude. On the concave surface of this hollow sphere thus surrounding us at an immeasurable distance all the stars appear to be placed. This sphere, carrying the whole creation upon it, appears to revolve round our world. It makes a complete revolution in twenty-four hours.* By this rotation, the diurnal appearances of the rising and setting of all the heavenly bodies are perfectly explained.

13. The ancients who, as has been stated, affirmed the reality of this motion of the celestial sphere, gave to the whole creation around the earth, the name UNIVERSE; from two words, UNUS, *one*, and VERSUM, *turning* or *rotation;* because they assumed that by an imaginary force, called the PRIMUM MOBILE, or *first impulse*, this rotatory motion had been imparted to the firmament, which ever afterwards retained it.

14. It is easy to perceive that the apparent diurnal rotation of the firmament round the earth may arise indifferently from either of two causes: 1st, from such a real rotation of the firmament

---

* More exactly $23^h\ 56^m\ 4{\cdot}09^s$, but for the present the cause of this difference need not be noticed.

once in twenty-four hours; 2ndly, from the rotation of the globe of the earth in the same time round that diameter which is in the direction of the axis round which the firmament appears to revolve.

There is absolutely no other supposition possible but one or other of these. The rejection of either necessarily throws us upon the adoption of the other.

But it may be required that we should show how the rotation of the earth upon an axis passing through the poles would cause the apparent diurnal rotation of the firmament.

15. Let us assume that the earth is a globe revolving uniformly on its axis in twenty-four hours. The universe around it is relatively stationary, and the bodies which compose it being at distances which mere vision cannot appreciate, appear as if they were situate on the surface of a vast celestial sphere in the centre of which the earth revolves. This rotation of the earth gives to the sphere the appearance of revolving in the contrary direction, as the progressive motion of a boat on a river gives to the banks an appearance of retrogressive motion; and since the apparent motion of the heavens is from east to west, the real rotation of the earth which produces that appearance must be from west to east.

How this motion of rotation explains the phenomena of the rising and setting of celestial objects is easily understood. An observer placed at any point upon the surface of the earth is carried round the axis in a circle in twenty-four hours, so that every side of the celestial sphere is in succession exposed to his view. As he is carried upon the side opposite to that in which the sun is placed, he sees the starry heavens visible in the absence of the splendour of that luminary. As he is turned gradually towards the side where the sun is placed, its light begins to appear in the firmament, the dawn of morning is manifested, and the globe continuing to turn, he is brought into view of the luminary itself, and all the phenomena of dawn, morning, and sunrise are exhibited. While he is directed towards the side of the firmament in which the sun is placed, the other bodies of inferior lustre are lost in the splendour of that luminary, and all the phenomena of day are exhibited. When by the continued rotation of the globe the observer begins to be turned away from the direction of the sun, that luminary declines, and at length disappears, producing all the phenomena of evening and sunset.

Such, in general, are the effects which would attend the motion of a spectator placed upon the earth's surface, and carried round with it by its motion of rotation. He is the spectator of a gorgeous diorama exhibited on a vast scale, the earth which forms his station being the revolving stage by which he is carried round, so as to view in succession the spectacle which surrounds him.

These appearances vary with the position assumed by the observer on this revolving stage; or, in other words, upon his situation on the earth, as will presently appear.

16. That diameter upon which it is necessary to suppose the earth to revolve in order to explain the phenomena is that which passes through the terrestrial poles.

17. If the globe of the earth be imagined to be cut by a plane passing through its centre at right angles to its axis, such a plane will meet the surface in a circle, which will divide it into two hemispheres, at the summits of which the poles are situate. This circle is called the TERRESTRIAL EQUATOR.

18. That hemisphere which includes the continent of Europe is called the NORTHERN HEMISPHERE, and the pole which it includes is called the NORTHERN TERRESTRIAL POLE; the other hemisphere being the SOUTHERN HEMISPHERE, and including the SOUTHERN TERRESTRIAL POLE.

19. If the surface of the earth be imagined to be intersected by planes passing through its axis, they will meet the surface in circles which, passing through the poles, will be at right angles to the equator. These circles are called TERRESTRIAL MERIDIANS, and will be seen delineated on any ordinary terrestrial globe.

These observations will be more clearly comprehended by reference to fig. 2, in which N is the north, and S the south pole of the earth, and Æ Q the equator. The firmament surrounding the earth is represented by the circle *n æ s q*. The axis S N of the earth being supposed to be prolonged to the heavens will meet the firmament at *n* and *s*, the celestial north and south poles; and in like manner the plane of the terrestrial equator Æ Q being continued to the heavens, will meet the firmament at *æ q*, the celestial equator.

If an observer be stationed at O, his zenith will be at *z*, and his horizon at *h h′*. As the globe revolves from west to east, the heavens will be successively brought into view on the east, and will disappear continually on the west.

20. Assuming then that all the diurnal changes of appearance presented by the firmament, the risings and settings of the sun, moon, and stars, and their varying appearance in different latitudes, admit of being explained with equal precision and completeness, either by supposing the universe to revolve daily round the earth, or the earth to revelve daily on its axis, the only question which remains to be decided is, which of these two suppositions is the more probable?

The fixity and absolute repose of the globe of the earth being assumed by the ancients as a physical maxim which did not even admit of being questioned, they perceived the inevitable character of the alternative which the apparent diurnal rotation of the heavens imposed upon them, and accordingly embraced the hypothesis, which now appears so monstrous, and which is implied in the term UNIVERSE, which they have bequeathed to us.

21. But with the knowledge which has been obtained by the labours of modern astronomers respecting the enormous magnitudes of the principal bodies of the physical universe, magnitudes compared with which that of the globe of the earth dwindles to a mere point, and their distances under the expression of which the very power of number itself almost fails, and recourse is had to colossal units in order to enable it to express even the smallest of them, the hypothesis of the immobility of the earth, and the diurnal rotation of the countless orbs of magnitudes so inconceivable filling the immensity of space once every twenty-four hours round this grain of matter composing our globe, becomes so preposterous that it is rejected, not as an improbability, but as an absurdity too gross to be even for a moment seriously entertained or discussed.

22. But if any ground for hesitation in the rejection of this hypothesis existed, all doubt would be removed by the simplicity and intrinsic probability of the only other physical cause which can produce the phenomena. The rotation of the globe of the earth upon an axis passing through its poles, with an uniform motion from west to east once in twenty-four hours, is a supposition against which not a single reason can be adduced based on improbability. Such a motion explains perfectly the apparent diurnal rotation of the celestial sphere. Being uniform and free from irregularities, checks, or jolts, it would not be perceivable by any local derangement of bodies on the surface of the earth, all of which would participate in it. Observers upon the surface of our globe would be no more conscious of it, than are the voyagers shut up in the cabin of a canal boat, or transported above the clouds in the car of a balloon.

23. It has been shown that a body descending from a great height does not fall in the true vertical line, which it would if the earth were at rest, but eastward of it, which it must, if the earth have a motion of rotation from west to east.

24. An ingenious expedient, by which the diurnal rotation of the earth is rendered visible, has been conceived and reduced to experiment by M. Leon Foucault. This contrivance is based upon the principle, that the direction of the plane of vibration of a pendulum is not affected by any motion of translation which may

be given to its point of suspension. Thus, if a pendulum suspended in a room and put into vibration in a plane parallel to one of the walls, be carried round a circular table, the plane of its vibration will continually be parallel to the same wall, and will therefore vary constantly in the angle it forms with the radius of the table which is directed to it.

Now, if a pendulum, suspended anywhere so near the pole of the earth that the circle round the pole may be considered a plane, be put in vibration in a plane passing through the pole, this plane, continuing parallel to its original direction as it is carried round the pole by the earth's rotation, will make a varying angle with the line drawn to the pole from the position it occupies. After being carried through a quarter of a revolution it will make an angle of 90° with the line to the pole, and so on. In fine, the direction of the pole will appear to be carried round the plane of vibration of the pendulum.

The same effects will be produced at greater distances from the pole, but the rate of variation of the angle under the plane of vibration and the plane of the meridian will be different, owing to the effects of the curvature of the meridian.

This phenomenon, therefore, being a direct effect of the rotation of the earth, supplies a proof of the existence of that motion, attainable without reference to objects beyond the limits of the globe.

25. Another evidence of the rotation of the earth upon its axis is derived from the ascertained fact that the planets which hold places in the solar system similar to that of the earth, do revolve on axes, in times not very different from that of the earth's rotation, as has been shown in our tract upon the Planets.

It may, then, be taken as proved that the earth is not fixed and quiescent, but that it has a rotatory motion round the diameter which passes through its poles, completing a revolution in a day.

26. Having explained the proofs by which we have arrived at the knowledge of the globular form of the earth, it may occasion some surprise that we shall now have to reconsider and modify that conclusion. In this there is nevertheless nothing unusual. It is quite in harmony with all the labours of those who devote themselves to the discovery of the laws of nature.

27. It is the condition of man, and probably of all other finite intelligences, to arrive at the possession of knowledge by the slow and laborious process of a sort of system of trial and error. The first conclusions to which, in physical enquiries, observation conducts us, are never better than very rough approximations to the truth. These, being submitted to subsequent comparison with the originals, undergo a first series of corrections, the more

prominent and conspicuous departures from conformity being removed. A second approximation, but still only an approximation, is thus obtained; and another and still more severe comparison with the phenomena under investigation is made, and another order of corrections is effected, and a closer approximation obtained. Nor does this progressive approach to perfect exactitude appear to have any limit. The best results of our intellectual labours are still only close resemblances to truth, the absolute perfection of which is probably reserved for a higher intellectual state.

These observations will be illustrated by the process of investigation and discovery in every department of physical science, but in none so frequently and so forcibly as in that which now occupies us.

The first conclusions at which we have arrived respecting the form of the earth is, that it is a globe; and with respect to its motion is, that it is in uniform rotation round one of its diameters, making one complete revolution daily.

28. The first question then which presents itself is, whether this form and rotation are compatible? It is not difficult to show, by the most simple principles of physics, that they are not; that with such a form such a rotation could not be maintained, and that with such a rotation such a form could not permanently continue.

The conclusion that the earth revolves on its axis with a motion corresponding to the apparent rotation of the firmament, is one which admits of no modification, and must from its nature be either absolutely admitted or absolutely rejected. The globular form imputed to the earth, however, has been inferred from observations of a general nature, unattended by any conditions of exact measurement, and which would be equally compatible with innumerable forms, departing to a very considerable and measurable extent from that of an exact geometrical sphere or globe.

29. It is a fact familiar to every one that when a body is whirled round in a circle it has a tendency to fly from the centre. This is called CENTRIFUGAL FORCE. If a stone be whirled round in a sling, this tendency is sensibly felt.

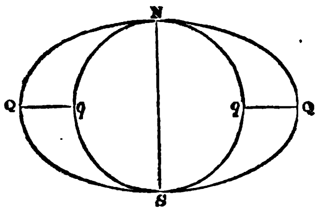
By reason of the rotation of the earth on its axis all the matter composing it, solid and fluid, being carried round the axis in circles of greater or less radius, has this tendency to fly from the axis round which it is thus whirled; and this tendency is stronger for those parts which are more distant than for those which are nearer to the common axis.

30. If the globe thus revolving were composed altogether of matter capable of yielding to the action of such forces, it would

obviously assume a form departing from that of an exact sphere. The parts near the equator would extend themselves to a greater distance from the axis, those more remote from the equator to a less distance, and so on, until, at the pole, the matter would not be at all affected by the rotation. This would be the case if the globe were formed of matter in a liquid or even in a semi-liquid or soft state, or if its materials were elastic.

The form it would take would be one resembling an orange or a turnip. Thus, if N S, fig. 3, be its axis, the equatorial diameter, *q q*, will be stretched out to the increased length, Q Q, while the parts between *q q* and the poles will be less and less extended the nearer they are to the poles, The globe would therefore be changed from the form N *q* S *q*. of a true sphere, to the form N Q S Q, of a flattened globe, called in geometry an OBLATE SPHEROID.

Fig. 3.



31. The elliptic form would depart more and more from a true circle as the motion of rotation is more rapid, so that between the time of rotation and the degree of ellipticity there is a fixed relation, such that when the time of rotation is given, the oval form, or what is the same, the proportion of the equatorial to the polar diameter, can be computed.

32. It is certain, then, that if the earth were composed of fluid, soft or elastic matter, it could not continue to retain the form of a globe, but would become a spheroid, having that degree of ellipticity which would correspond to a motion of rotation, at the rate of one revolution per day, and it is shown by calculation that this ellipticity would be such that the equatorial diameter would be greater than the polar diameter by one three-hundredth part.

33. But the earth, in its present state, is not composed of such yielding materials, and it becomes a question, what, in that case, must be the effect of the diurnal rotation on the distribution of land and water, if the earth were an exact globe.

34. The solid parts of the earth would resist by their cohesion the tendency of the rotation, to cause them to be accumulated and heaped up around the equator; but this would not be the case with the waters composing the seas and oceans. These, by reason of their freedom and mobility would yield to the centrifugal force, and would heap themselves up around the equator, flowing in that direction from the polar regions of either hemisphere, so that the necessary consequences of the earth having a form exactly

globular, and a diurnal rotation, would be that the surface would consist of two vast polar continents separated by an extensive equatorial ocean.

Such not being the distribution of land and water on the earth, it follows that its form cannot be that of an exact globe.

35. It remains, then, to find means to ascertain by direct measurement and observation, what is the actual form of the earth.

If a terrestrial meridian were an exact circle, as it would necessarily be if the earth were an exact globe, every part of it would have the same curvature. But if it were an ellipse, of which the polar diameter is the lesser axis, it would have a varying curvature, the convexity being greatest at the equator, and least at the poles. If, then, it can be ascertained by observation, that the curvature of a meridian is not uniform, but that on the contrary it increases in going towards the Line, and diminishes in going towards the Poles, we shall obtain a proof that its form is that of an oblate spheroid.

To comprehend the method of ascertaining this, it must be considered that the curvature of circles diminishes as their diameters are augmented.

If, therefore, a degree of the meridian be observed, and measured, at different latitudes, and it is found that its length is not uniformly the same as it would be if the meridian were a circle, but that it is less in approaching the equator, and greater in approaching the pole, it will follow that the convexity or curvature increases towards the equator, and diminishes towards the poles; and that consequently the meridian has the form, not of a circle, but of an ellipse, the lesser axis of which is the polar diameter.

Such observations have accordingly been made, and the lengths of a degree in various latitudes, from the Line to 66° N. and to 35° S., have been measured, and found to vary from 363000 feet on the Line to 367000 feet at lat. 66°.

From a comparison of such measurements, it has been ascertained that the equatorial diameter of the spheroid exceeds the polar by $\frac{1}{300}$th of its length.

Now this is precisely the form, precisely the degree of ellipticity, which a globe, composed of fluid or soft materials, would assume if it had a rotation on its axis once in twenty-four hours.

Thus it appears, that the form of the earth, ascertained by observation, supplies another proof of its diurnal rotation.

36. It is not enough to know the proportions of the earth. It is required to determine the actual dimensions of the spheroid. The following are the lengths of the polar and equatorial diameters,

according to the computations of the most eminent and recent authorities :—

	BESSEL.	AIRY.
	Miles.	Miles.
Polar diameter	7899·114	7899·170
Equatorial diameter	7925·604	7925·648
Absolute difference	26·471	26·478
Excess of the equatorial expressed in a fraction of its entire length . . .	$\frac{1}{299{\cdot}407}$	$\frac{1}{299{\cdot}330}$

The close coincidence of these results supplies a striking example of the precision to which such calculations have been brought.

37. The departure of the terrestrial spheroid from the form of an exact globe is so inconsiderable that, if an exact model of it turned in ivory were placed before us, we could not, either by sight or touch, distinguish it from a perfect billiard ball. A figure of a meridian actually drawn on paper could only be distinguished from a circle by the most precise measurement.

38. The magnitude of the earth being known with great precision, the determination of its mass and that of its mean density become one and the same problem, since the comparison of its mass with its magnitude will give its mean density, and the comparison of its mean density with its magnitude will give its mass.

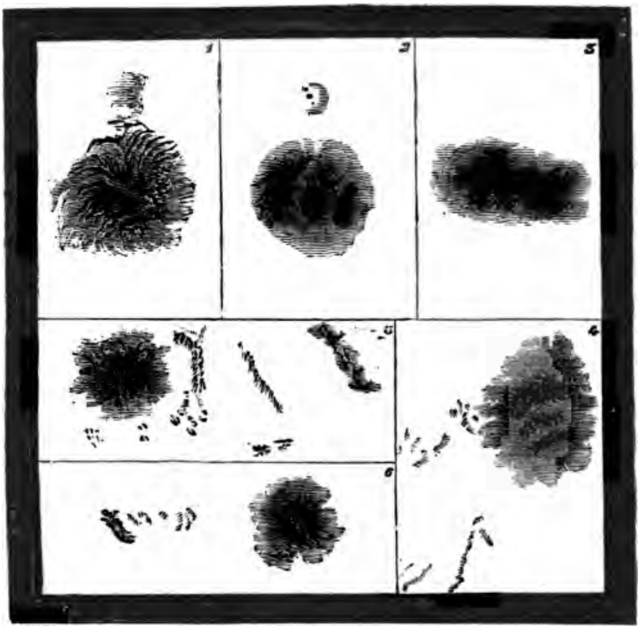
The methods of ascertaining the mass or actual quantity of matter contained in the earth are all based upon a comparison of the gravitating force or attraction which the earth exerts upon an object with the attraction which some other body, whose mass is exactly known, exerts on the same object. It is assumed, as a postulate or axiom in physics, that two masses of matter which at equal distances exert equal attractions on the same body, must be equal. But as it is not always possible to bring the attracting and attracted bodies to equal distances, their attractions at unequal distances may be observed, and the attractions which they would exert at equal distances may be thence inferred by the general law of gravitation, by which the attraction exerted by the same body increases as the square of the distance from it is diminished.

39. To solve this celebrated problem, it is necessary to bring the whole mass of the globe into direct comparison with some object whose mass is exactly known. This was accomplished first by Dr. Maskelyne, and afterwards by Cavendish. The former compared the attraction of the earth with that of a mountain in Perthshire, called Schehallion; the latter compared it with the attraction of a large ball of metal. Both obtained nearly the

same result, showing that the earth is a mass of matter about 5⅔ heavier than an equal volume of water, or, what is the same, that the mean density of the earth is 5⅔, or, more exactly, 5·67 times the density of water.

Among the substances which have nearly the same density as the earth may be mentioned, arsenic, chromium, chloride of silver, oxides of copper and zinc, and peroxide of iron.

40. The average weight of each cubic foot of the earth being 5·67 times the weight of a cubic foot of water, is 354·375 lbs., or 0·1587 of a ton. It follows, therefore, that the total weight of the earth is more than 6000,000000 billions of tons.



SOLAR SPOTS OBSERVED IN 1826 AND 1828 BY MM. CAPOCCI AND PASTORFF.

Capocci—1. Sept. 29; 2. Sept. 2; 3. July 1, 1826.
Pastorff—4. Sept. 27, 1826; 5. May 21; 6. June 21, 1828.

THE SUN.

1. An object of great interest.—2. Its distance.—3. Magnitude.—4. Illustrations.—5. Its volume.—6. Mass or weight.—7. How ascertained.—8. Application of this principle.—9. Its density.—10. Form and rotation.—11. Determined by the appearance of spots.—12. Discovery of Solar spots.—13. Their great magnitude.—14. Their rapid changes.—15. Hypotheses to explain them.—16. They are excavations in the luminous coating.—17. Their prevalence varies.—18. Observations upon them.—19. Their dimensions.—20. Facules and Lucules.—21. Physical state of the Solar surface.—22. Luminous coating is gaseous.—23. Gaseous atmosphere outside it.—24. Effects of such an atmosphere on radiation.—25. Hypothesis of Sir J. Herschel.—26. Intensity of heat at Sun's surface.—27. Supposed source of heat.

1. ALTHOUGH perhaps the moon is the object among the heavenly bodies which presents the subject of most interesting inquiry to the world in general, yet, to the thoughtful and contemplative

mind, the sun is undoubtedly one of vastly superior interest. The sun—the fountain of light and life to a family of circumvolving worlds—the inexhaustible store of genial warmth by which the countless tribes of organised beings that people these globes are sustained—the physical bond whose predominating attraction gives stability, uniformity, and harmony, to the movements of the entire planetary system: to collect together in a brief compass the information which modern scientific research has supplied relating to this body, cannot be otherwise than an interesting and agreeable task.

2. When we direct our inquiries to any object in the heavens, the first questions which present themselves naturally to us are, "What is its distance, magnitude, motion, and position?" When we say that the distances of the bodies composing the solar system can be measured with the same degree of relative accuracy with which we ascertain the distances of bodies on the surface of the earth, those who are unaccustomed to investigations of this kind usually receive the statement with a certain degree of doubt and incredulity; they cannot conceive how such spaces can be accurately measured, or indeed measured at all. Thus, when they are told that the sun is at a distance from the earth amounting to nearly 100,000000 of miles, the mind revolts from the idea that such a space could be exactly ascertained and estimated. Yet, let us ask, why this difficulty? whence this incredulity? Is it because the distance thus measured is enormously great,—greater transcendently than any distance we are accustomed to contemplate upon our own globe? To this we reply that the magnitude of a distance or space does not constitute of itself any difficulty in its admeasurement. Nay, on the contrary, it is often the case that we are able to measure large distances with greater relative accuracy than small ones; this is frequently so in the surveys conducted on the surface of our own globe. If, then, the greatness of the magnitudes does not constitute of itself any difficulty, to what are we to ascribe the doubt entertained by the popular mind in regard to such measurement? It will, perhaps, be replied that the object, whose distance we claim to have measured, is inaccessible to us; that we cannot travel over the intermediate space, and therefore cannot be conceived to measure it. But again, let us ask whether this circumstance of being inaccessible constitutes any real difficulty in the measurement of the distance of an object? The military engineer, who directs his projectiles against the buildings within a town which is besieged, can, as we well know, level them so as to cause a shell to drop on any individual building which may have been chosen. To do this, he must know the exact distance of the building from

the mortar. Yet the building is inaccessible to him; the walls of the town, the fortifications, and perhaps a river, intervene. He finds, however, no difficulty in measuring the distance of this inaccessible building. To accomplish this, he lays down a space upon the ground he occupies, called the *base* line, from the extremities of which he takes the bearings or directions of the building in question. From these bearings, and from the length of the base line, he is enabled to calculate by the most simple principles of geometry and arithmetic the distance of the building in question. Now imagine the building in question to be the sun, and the base line to be the whole diameter of the globe of the earth, in what respect would the problem be altered? The building within the town is inaccessible—so is the sun; the base line of the engineer is exactly known—so is the diameter of the earth; the bearings of the building from the ends of the base line are known—so are the bearings of the sun's centre from the extremes of the earth's diameter. The problems are, in fact, identical; they differ in nothing except the accidental and unimportant circumstance of the magnitudes of the lines and angles that enter the question. In short, the measurement of distances of objects in the heavens is effected upon principles in all respects similar to those which govern the measurement of distances upon the earth; nor are they attended with a greater difficulty, or more extensive sources of error.

By such means of observation and calculation it has been ascertained that the sun's distance from the earth is a little less than an hundred millions of miles. Although such calculations supply results having surprising arithmetical accuracy, the ordinary student will always find it convenient to register in his memory the results in the nearest round numbers, and it is not easy to forget that the distance of the sun, the most important of all astronomical measurements, is very nearly an hundred millions of miles.

But while this round result is remembered, it will also be useful to explain the more exact numerical measure of this distance, and the limits of the error to which it is subject. The result of the most exact observations made upon the different bearings of lines drawn from opposite sides of the earth to the sun, gives as the distance of that luminary,

95,293452 miles,

and it has been proved that this result cannot be greater or less than the true distance by more than its three hundredth part. We are, therefore, enabled to affirm absolutely that the distance of the sun cannot be greater than

$$95,293452 + 317645 = 95,611097 \text{ miles};$$

or less than

$$95,293452 - 317645 = 94,975807 \text{ miles}.$$

Since the sun moves over 360° of the heavens in $365\frac{1}{4}$ days, its daily apparent motion must be $59'\cdot14$, or $3548''$, which being about twice the sun's apparent diameter, it is easy to remember that the disk of the sun appears to move in the firmament daily over a space nearly equal to twice its own apparent diameter. Its hourly apparent motion is

$$\frac{3548''}{24}=147''\cdot8.$$

3. Having explained the distance of the sun, let us now see how its magnitude can be ascertained. There is one general principle by which the magnitudes of all the heavenly bodies can be ascertained when their distance is known. This is, in fact, accomplished by the device of comparing them with some object of known magnitude and which at any known distance will have the same apparent size. As this is important, considered as a general principle applied to all objects in the heavens, it may not be uninteresting to develop it somewhat fully in its application to the present object, the sun.

The common observation of every one who directs his view to the heavens, will inform him of the fact that the sun and full moon appear to be of the same size. The mere effect of ordinary visual observation is, perhaps, enough to establish this; but if more be desired, instruments expressly adapted to measure the apparent magnitudes of objects may be applied. We are also confirmed in the fact by the consideration of the well-known phenomena of solar eclipses. A solar eclipse is produced by the interposition of the globe of the moon between the eye and the globe of the sun. The eclipse is said to be central when the centre of the moon is directly in line between the eye and the centre of the sun. When this takes place we find that the globe of the moon generally covers pretty exactly that of the sun. Owing, however, to a slight variation in the apparent size of these bodies, from a cause that we shall explain on another occasion, the moon at one time a little more than covers the sun, and at another time a little less. In short, the average apparent magnitudes of these bodies are the same, the one exactly covering or concealing the other.

But we have already stated that the distance of the moon is only a quarter of a million of miles. And since that of the sun is an hundred millions of miles, it appears that the distance of the sun is four hundred times greater than that of the moon; yet these two globes appear to the eye to be of the same magnitude. The sun, notwithstanding its being four hundred times farther off, appears just as large as the moon. What, then, are we to infer respecting its real magnitude? If the sun were really equal in magnitude to the moon, it would assuredly appear four hundred times less at four hundred times a greater distance: but since at that greater distance it does not appear less or greater, but of the same magnitude, the irresistible conclusion, level to the apprehension of any understanding, is, that the sun must in reality be four hundred times greater in its diameter than the moon. If it were less, at four hundred times the moon's distance, it would appear less than that of the moon; if it were greater, at that distance it would appear greater. It follows, then, that whatever be the magnitude of the diameter of the moon, the diameter of the sun must assuredly be four hundred times greater. Now it has been ascertained by absolute measurement that the diameter of the moon measures about 2000 miles. If we multiply this by four hundred we shall obtain 800000 miles, which is, therefore, the diameter of the sun.

These calculations have been made roughly and in round numbers; more accurately, the diameter of the sun measures 882000 miles, but as we recommend the adoption of round numbers, we shall call the sun's diameter 900000 miles. Such is the stupendous mass placed in the centre of the system which, by its attraction, coerces the movements of the planets.

4. Such magnitudes and distances are so far beyond all the ordinary standards with which we are familiar, that the imagination is confounded and falls back upon itself after any effort to form a distinct conception of them. Let us see whether we cannot discover some expedient or some means of illustration by which a more distinct notion can be obtained of the distance and magnitude of this stupendous globe.

A railway-train moving at thirty-two miles an hour would take three millions of hours or an hundred and twenty-five thousand days, or three hundred and forty-two years and three months to move from the earth to the sun, supposing it to travel incessantly night and day for that time!

A cannon ball moves fifty times as fast as such a railway train. It would therefore move to the sun in a little less than seven years!

To give some idea of the dimensions of the sun we are to consider that having a diameter of 882000 miles, its circumference will be about 2,770000 miles. Such a railway-train would take nine years and ten months to travel round it.

We know that the moon revolves in a circle round the earth at the distance of nearly a quarter of a million of miles. Now let us suppose the earth to be placed at the centre of the sun. The distance of the outer surface of the sun from the centre of the earth would be 441000 miles. Now the circle in which the moon revolves round the earth, is at a distance of 240000 miles from its centre, consequently it follows that the earth and moon would be not only contained within the globe of the sun, but the moon would be a couple of hundred thousand miles within the sun's surface.

5. But we have hitherto only spoken of the diameter of the sun; let us now consider its bulk. When we know the diameters of two globes we can always, by an easy operation of arithmetic, estimate their bulks. Thus, if one globe have a diameter double another, the bulk of the former will be eight times that of the latter. If the diameter be ten times greater, the bulk will be a thousand fold greater, and so on. Now we know that the diameter of the sun is about one hundred and twelve times greater than that of the earth, from which we infer, by the same principles of arithmetic, that the bulk of the sun must be very nearly one million four hundred thousand times the bulk of the earth. To make a globe like the sun, it would then be necessary to roll one million four hundred thousand globes like the earth into one! It is found by considering the bulks of the different planets, that if all the planets and satellites in the solar system were moulded into a single globe, that globe would still not exceed the five hundredth part the globe of the sun: in other words, the bulk of the sun is five hundred times greater than the aggregate bulk of all the rest of the bodies of the system.

6. The astronomer, however, is called upon to execute processes more difficult and yet no less indispensable than the mere measurement of distances and magnitudes. If we desire to know the quantities of matter composing those distant orbs, we must not merely measure their magnitudes and fathom their distances, but we must wing our flight, in imagination, across those vast distances which separate us from them and *weigh* their stupendous masses. If the popular student finds it difficult to believe and comprehend how we can measure distances and magnitudes such as those of the heavenly bodies, how much more will he be confounded when he is assured that we have at our disposal a balance of the most unerring exactitude in which we can place those vast orbs and poise them! The globe of the sun itself, transcendently greater than the earth and all the planets put together, is weighed with as great relative precision, as that with which the chemist in his analysis, estimates the weights of the constituents of the bodies which pass under his hands. As the general principles by which the weights of the bodies of the universe are ascertained is in spirit the same for all, it may be worth while here to explain the method, once for all, in its application to the sun.

7. When a body revolves in a circle, we know from common

and familiar experiments that it has a tendency to fly from the centre, which tendency is greater the more rapidly the body revolves and the greater its distance from the centre. The boy who whirls a stone in a sling is conscious of this physical truth. The stone, as it revolves, stretches the string with a certain definite force; this force is not in the gravity of the stone, for it would be equally manifested if the stone revolved in a horizontal plane. It is that tendency which we have just adverted to, and which is technically called centrifugal force. If you increase the velocity with which the stone is whirled round, you will find the string will be more and more tightly stretched, and you may augment the velocity to such an extent as to break the string. If you lengthen or shorten the string, preserving the same velocity of rotation, you will find that the tendency to stretch the string will be proportionally increased or diminished; in short, a fixed rule or *law*, as it is called, will be easily discovered by a series of simple experiments which will enable us to predict how much the string will be stretched, provided we know the distance of the revolving weight from the centre of the circle and the time it takes to make each revolution.

8. To apply this general principle, then, to the case before us, let it be considered that the moon in its monthly course revolves in a circle round the centre of the earth. We know its distance, and we know the time which it takes to make each revolution, we are therefore in a condition to declare with what force it would stretch a string, tying it to the centre of the earth. That the moon exercises such a force cannot then be doubted. But on what, it will be asked, is that force expended? There is no string, rod, or any other material or tangible connection between the moon and the centre of the earth. And yet the moon is held as firmly and steadily in its circular course round the earth, as if it were tied to the centre by a string. In the absence of the string there must then be some physical agency which plays its part; there must be something to resist that tendency which the string, if there, would have resisted. That *something* was discovered by Newton to be the attraction of the earth's GRAVITATION exercised upon the moon and holding the moon in its circular orbit, in the same manner that it would be held by the string which has been just described. As we know, by the simple mechanical law above explained, the force with which that string would be stretched by the moon in this case, we are enabled by the same principle to say what is the amount of attractive force which the earth exercises upon the moon to keep it in its monthly orbit.

In this manner, in general, we are enabled to estimate the force of attraction which a central mass exercises upon another body revolving in a circle round it at a known distance, and in a known time.

While, on the one hand, we know the distance and time of the moon's revolution round the earth, we also know the distance and time of the earth's revolution round the sun. We are thus, allowing for the difference of the two distances, in a condition to compare the actual amount of attraction which the earth and the sun respectively exercise upon bodies revolving round them, and we find, accordingly, that the attraction exercised by the sun upon any body is greater than the attraction that would be exercised by the earth upon the same body in a like position, in the proportion of three hundred and fifty thousand to one. But as these attractions are, in fact, produced by the respective masses of matter composing the sun and the earth, it follows that the weight of the sun, or what is the same, the mass of matter composing it, is three hundred and fifty thousand times greater than the mass of matter or weight of the earth.

To make a globe as heavy as the sun, it would then be necessary to agglomerate into one three hundred and fifty thousand globes like the earth.

9. Having ascertained the weights and bulks of the bodies of the universe, we are in a condition to determine their densities, and thus to obtain some clue to a knowledge of their constituent materials. We have seen that while the bulk of the sun is about one million and four hundred thousand times greater than that of the earth, its weight is greater in the much less proportion of three hundred and fifty thousand to one. Let us see to what inference this leads in regard to the nature of the matter that composes the sun. If the materials of the sun were similar to those of the earth, its weight would necessarily be greater than that of the earth in the same proportion as its bulk, and in that case, of course, the weight of the sun would be one million and four hundred thousand times that of the earth. But it is not nearly so great as this; on the contrary, it is much less. Consequently, it follows that the constituent materials of the sun are lighter than those of the earth in the proportion of about four to one. The density of the sun is, therefore, about forty per cent. greater than that of water, and, consequently, the weight of the solar orb exceeds the weight of a globe of the same magnitude composed altogether of water, only in that proportion.

10. Although to minds unaccustomed to the rigour of scientific research, it might appear sufficiently evident, without further demonstration, that the sun is globular in its form, yet the more exact methods pursued in the investigation of physics demand that we should find more conclusive proof of the sphericity of the

solar orb than the mere fact that the disc of the sun is always circular. It is barely possible, however improbable, that a flat circular disc of matter, the face of which should always be presented to the earth, might be the form of the sun; and indeed there are a great variety of other forms which, by a particular arrangement of their motions, might present to the eye a circular appearance as well as a globe or sphere. To prove, then, that a body is globular, something more is necessary than the mere fact that it always appears circular.

11. When a telescope is directed to the sun, we discover upon it certain marks or spots, of which we shall speak more fully presently. We observe that these marks, while they preserve the same relative position with respect to each other, move regularly from one side of the sun to the other. They disappear, and continue to be invisible for a certain time, come into view again on the other side, and so once more pass over the sun's disc. This is an effect which would evidently be produced by marks on the surface of a globe, the globe itself revolving on an axis, and carrying these marks upon it. That this is the case, is abundantly proved by the fact that the periods of rotation for all these marks are found to be exactly the same, viz., about twenty-five and a half days. Such is, then, the time of rotation of the sun upon its axis, and that it is a globe remains no longer doubtful, since the globe is the only body which, while it revolves with a motion of rotation, could always present the circular appearance to the eye. The axis on which the sun revolves is very nearly perpendicular to the plane of the earth's orbit, and the motion of rotation of the sun upon the axis is in the same direction as the motion of the planets round the sun, that is to say, from west to east.

12. One of the earliest fruits of the invention of the telescope was the discovery of the spots upon the sun, and the examination of these has gradually led to a knowledge of the physical constitution of the centre of our system.

When we submit a solar spot to telescopical examination, we discover its appearance to be that of an intensely black irregularly-shaped patch, edged with a penumbral fringe, the brightness of the general surface of the sun gradually fading away into the blackness of the spot. When watched for a considerable time, it is found to undergo a gradual change in its form and magnitude; at first increasing in size, until it attains some definite limit of magnitude, when it ceases to increase, and soon begins, on the contrary, to diminish; and its diminution goes on gradually, until at length the bright edges closing in upon the dark patch, it dwindles first to a mere point, and finally disappears altogether.

The period which elapses between the formation of the spot, its gradual enlargement, subsequent diminution, and final disappearance, is very various. Some spots appear and disappear very rapidly, while others have lasted for weeks and even for months.

13. The magnitudes of the spots, and the velocities with which the matter composing their edges and fringes moves, as they increase and decrease, are on a scale proportionate to the dimensions of the orb of the sun itself. When it is considered that a space upon the sun's disc, the apparent breadth of which is only a minute, actually measures 27960 miles, and that spots have been frequently observed, the apparent length and breadth of which have exceeded 2′, the stupendous magnitude of the regions they occupy may be easily conceived.

14. The velocity with which the luminous matter at the edges of the spots occasionally moves, during the gradual increase or diminution of the spot, has been in some cases found to be enormous. A spot, the apparent breadth of which was 90″, was observed by Mayer to close in about 40 days. Now, the actual linear dimensions of such a spot must have been 41940 miles, and consequently, the average daily motion of the matter composing its edges must have been 1050 miles, a velocity equivalent to forty-four miles an hour.

15. Two, and only two, suppositions have been proposed to explain the spots. One supposes them to be scoriæ, or dark scales of incombustible matter, floating on the general surface of the sun. The other supposes them to be excavations in the luminous matter which coats the sun, the dark part of the spot being a part of the solid non-luminous nucleus of the sun. In this latter hypothesis it is assumed that the sun is a solid non-luminous globe, covered with a coating of a certain thickness of luminous matter.

That the spots are excavations, and not mere black patches on the surface, is proved by the following observations: If we select a spot which is at the centre of the sun's disc, having some definite form, such as that of a circle, and watch its changes of appearance, when, by the rotation of the sun, it is carried towards the edge, we find, first, that the circle becomes an oval. This, however, is what would be expected, even if the spot were a circular patch, inasmuch as a circle seen obliquely is foreshortened into an oval. But we find that as the spot moves towards the side of the sun's limb, the black patch gradually disappears, the penumbral fringe on the inside of the spot becomes invisible, while the penumbral fringe on the outside of the spot increases in apparent breadth, so that when the spot approaches the edge of the sun, the only part that is visible is the external penumbral fringe. Now, this is exactly what would occur if the spot were an excavation. The penumbral fringe is produced by the shelving of the sides of the excavation, sloping down to its dark bottom. As the spot is carried toward the edge of the sun, the height of the inner side is interposed between the eye and the bottom of the excavation, so as to conceal the latter from view. The surface of the inner shelving side also taking the direction of the line of vision or very nearly, diminishes in apparent breadth, and ceases to be visible, while the surface of the shelving side next the edge of the sun becoming nearly perpendicular to the line of vision, appears of its full breadth.

In short, all the variations of appearance which the spots undergo, as they are carried round by the rotation of the sun, changing their distances and positions with regard to the sun's centre, are exactly such as would be produced by an excavation, and not at all such as a dark patch on the solar surface would undergo.

16. It may be considered then as proved, that the spots on the sun are excavations; and that the apparent blackness is produced by the fact that the part constituting the dark portion of the spot is either a surface totally destitute of light, or by comparison so much less luminous than the general surface of the sun, as to appear black. This fact, combined with the appearance of the penumbral edges of the spots, has led to the supposition, advanced by Sir W. Herschel, which appears scarcely to admit of doubt, that the solid, opaque nucleus, or globe of the sun, is invested with at least two atmospheres, that which is next the sun being, like our own, non-luminous, and the superior one being that alone in which light and heat are evolved; at all events, whether these strata be in the gaseous state or not, the existence of two such, one placed above the other, the superior one being luminous, seems to be exempt from doubt.

We are not warranted in assuming that the black portion of the spots are surfaces really deprived of light, for the most intense artificial lights which can be produced, such, for example, as that of a piece of quicklime exposed to the action of the compound blow-pipe, when seen projected on the sun's disk, appear as dark as the spots themselves; an effect which must be ascribed to the infinitely superior splendour of the sun's light. All that can be legitimately inferred respecting the spots, then, is, not that they are destitute of light, but that they are incomparably less brilliant than the general surface of the sun.

17. The prevalence of spots on the sun's disk is both variable and irregular. Sometimes the disk will be completely divested of them, and will continue so for weeks or months; sometimes they will be spread over certain parts of it in profusion. Sometimes the spots will be small, but numerous; sometimes individual spots will

appear of vast extent; sometimes they will be manifested in groups, the penumbræ or fringes being in contact.

The duration of each spot is also subject to great and irregular variation. A spot has appeared and vanished in less than twenty-four hours, while some have maintained their appearance and position for nine or ten weeks, or during nearly three complete revolutions of the sun upon its axis.

A large spot has sometimes been observed suddenly to crumble into a great number of small ones.

The only circumstance of regularity which can be said to attend these remarkable phenomena is their position upon the sun. They are invariably confined to two moderately broad zones parallel to the solar equator, separated from it by a space several degrees in breadth. The equator itself, and this space which thus separates the macular zones, are absolutely divested of such phenomena.

18. Observations upon the appearances from which these inferences have been made, have been at various times made by astronomers, the most important being those of Sir William Herschel, Dr. Pastorff, Professor Capocci, and Sir J. Herschel, who have severally supplied drawings of their appearance, the general similarity of which, made at different places of observation, at very different times, and by different observers, offers a strong evidence of their authenticity.

In the figure at the head of this chapter, we have given copies of several of the most remarkable of these drawings.

19. The superficial dimensions of the several groups of spots observed on the sun on the 24th May, 1828, including the shelving sides, were calculated to be as follows :—

	Square Geog. miles.
Group A, principal spot	928,000000
Ditto, smaller spots	736,000000
Group B	296,000000
Group C	232,000000
Group D	304,000000
Total area	2496,000000

20. Independently of the dark spots just described, the luminous part of the solar disk is not uniformly bright. It presents a mottled appearance, which may be compared to that which would be presented by the undulated and agitated surface of an ocean of liquid fire, or to a stratum of luminous clouds of varying depth, and having an unequal surface, or the appearance produced by the slow subsidence of some flocculent chemical precipitates in a transparent fluid, when looked at perpendicularly from above. In the space immediately around the edges of the spots extensive

spaces are observed, also covered with strongly defined curved or branching streaks, more intensely luminous than the other parts of the disk, among which spots often break out. These several varieties in the intensity of the brightness of the disk have been differently designated by the terms *facules* and *lucules*. These appearances are generally more prevalent and strongly marked near the edges of the disk.

21. Various attempts have been made to ascertain by the direct test of observation, independently of conjecture or hypothesis, the physical state of the luminous matter which coats the globe of the sun, whether it be solid, liquid, or gaseous.

That it is not solid is admitted to be proved conclusively by its extraordinary mobility, as indicated by the rapid motion of the edges of the spots in closing; and it is contended that a fluid capable of moving at the rate of 44 miles per hour cannot be supposed to be liquid, an elastic fluid alone admitting of such a motion.

Arago has, however, suggested a physical test, by which it appears to be proved that this luminous matter must be gaseous; in short, that the sun must be invested with an ocean of flame, since flame is nothing more than aëriform fluid in a state of incandescence. This test proposed is based upon the properties of polarised light.

It has been proved that the light emitted from an incandescent body in the liquid or solid state, issuing in directions very oblique to the surface, even when the body emitting it is not smooth or polished, presents evident marks of polarisation, so that such a body, when viewed through a polariscopic telescope, will present two images in complementary colours. But, on the other hand, no signs of polarisation are discoverable, however oblique may be the direction in which the rays are emitted, if the luminous matter be flame.

The light proceeding from the disk of the sun has been accordingly submitted to this test. The rays proceeding from its borders evidently issue in a direction as oblique as possible to the surface, and therefore, under the condition most favourable to polarisation, if the luminous matter were liquid. Nevertheless, the borders of the double image produced by the polariscope show no signs whatever of complementary colours, both being equally white even at the very edges.

This test is only applicable to the luminous matter at or near the edge of the disk, because it is from this only that the rays issue with the necessary obliquity. But since the sun revolves on its axis, every part of its surface comes in succession to the edge of the disk; and thus it follows that the light emanating from every part of it is in its natural or unpolarised state, even when issuing at the greatest obliquity; and, consequently, that the luminous matter is everywhere gaseous.

22. All the phenomena which have been here described, and others which our limits compel us to omit, are considered as giving a high degree of physical probability to the hypothesis of Sir W. Herschel already noticed, in which the sun is considered to be a solid, opaque, non-luminous globe invested by two concentric strata of gaseous matter, the first, or that which rests immediately on the surface, being non-luminous, and the other, which floats upon the former, being luminous gas or flame. The relation and arrangement of these two fluid strata may be illustrated by our own atmosphere, supporting upon it a stratum of clouds. If such clouds were flame, the condition of our atmosphere would represent the two strata on the sun.

The spots in this hypothesis are explained by occasional openings in the luminous stratum by which parts of the opaque and non-luminous surface of the solid globe are disclosed. These partial openings may be compared to the openings in the clouds of our sky, by which the firmament is rendered partially visible.

23. Many circumstances supply indications of the existence of a gaseous atmosphere of great extent above the luminous matter which forms the visible surface of the sun. It is observed that the brightness of the solar disk is sensibly diminished towards its borders. This effect would be produced if it were surrounded by an imperfectly transparent atmosphere, whereas if no such gaseous medium surrounded it, the reverse of such an effect might be expected, since then the thickness of the luminous coating measured in the direction of the visual ray would be increased very rapidly in proceeding from the centre towards the edges. This gradual diminution of brightness in proceeding towards the borders of the solar disk has been noticed by many astronomers; but it was most clearly manifested in the series of observations made by Sir J. Herschel in 1837, so conclusively, indeed, as to leave no doubt whatever of its reality on the mind of that eminent observer. By projecting the image of the sun's disk on white paper by means of a good achromatic telescope, this diminution of light towards the borders was on that occasion rendered so apparent, that it appeared to him surprising that it should ever have been questioned.

But the most conclusive proofs of the existence of such an external atmosphere are supplied by certain phenomena observed on the occasion of total eclipses of the sun, which will be fully explained in another part of this series.

24. The heat generated by some undiscovered agency upon the

sun is dispersed through the surrounding space by radiation. If, as may be assumed, the rate at which this heat is generated be the same on all parts of the sun, and if, moreover, the radiation be equally free and unobstructed from all parts of its surface, it is evident that a uniform temperature must be everywhere maintained. But if, from any local cause, the radiation be more obstructed in some regions than in others, heat will accumulate in the former, and the local temperature will be more elevated there than where the radiation is more free.

But the only obstruction to free radiation from the sun must arise from the atmosphere with which to an height so enormous it is surrounded. If, however, this atmosphere have everywhere the same height and the same density, it will present the same obstruction to radiation, and the effective radiation which takes place through it, though more feeble than that which would be produced in its absence, is still uniform.

But since the sun has a motion of rotation on its axis in $25^{d\cdot}\ 7^{h\cdot}\ 48^{m\cdot}$, its atmosphere, like that of the earth, must participate in that motion and the effects of centrifugal force upon matter so mobile: the equatorial zone being carried round with a velocity greater than 300 miles per second, while the polar zones are moved at a rate indefinitely slower, all the effects to which the spheroidal form of the earth is due will affect this fluid with an energy proportionate to its tenuity and mobility, the consequence of which will be that it will assume the form of an oblate spheroid, whose axis will be that of the sun's rotation. It will flow from the poles to the equator, and its height over the zones contiguous to the equator will be greater than over those contiguous to the poles, in a degree proportionate to the ellipticity of the atmospheric spheroid.

Now, if this reasoning be admitted, it will follow that the obstruction to radiation produced by the solar atmosphere is greatest over the equator, and gradually decreases in proceeding towards either pole. The accumulation of heat, and consequent elevation of temperature, is, therefore, greatest at the equator, and gradually decreases towards the poles, exactly as happens on the earth from other and different physical causes.

25. The effects of this inequality of temperature, combined with the rotation, upon the solar atmosphere, will of course be similar in their general character, and different only in degree from the phenomena produced by the like cause on the earth. Inferior currents will, as upon the earth, prevail towards the equator, and superior counter-currents towards the poles. The spots of the sun would, therefore, be assimilated to those tropical regions of the earth in which, for the moment, hurricanes and tornadoes prevail, the upper stratum which has come from the equator being

temporarily carried downwards, displacing by its force the strata of luminous matter beneath it (which may be conceived as forming an habitually tranquil limit between the opposite upper and under currents), the upper of course to a greater extent than the lower, and thus wholly or partially denuding the opaque surface of the sun below. Such processes cannot be unaccompanied by vorticose motions, which, left to themselves, die away by degrees, and dissipate, with this peculiarity, that their lower portions come to rest more speedily than their upper, by reason of the greater distance below, as well as the remoteness from the point of action, which lies in a higher region, so that their centre (as seen in our water-spouts, which are nothing but small tornadoes) appears to retreat upwards.*

Sir J. Herschel maintains that all this agrees perfectly with what is observed during the obliteration of the solar spots, which appear as if filled in by the collapse of their sides, the penumbra closing in upon the spot and disappearing afterwards.

It would have rendered this ingenious hypothesis still more satisfactory, if Sir J. Herschel had assigned a reason why the luminous and subjacent non-luminous atmosphere, both of which are assumed to be gaseous fluids, do not affect, in consequence of the rotation, the same spheroidal form which he ascribes to the superior solar atmosphere.

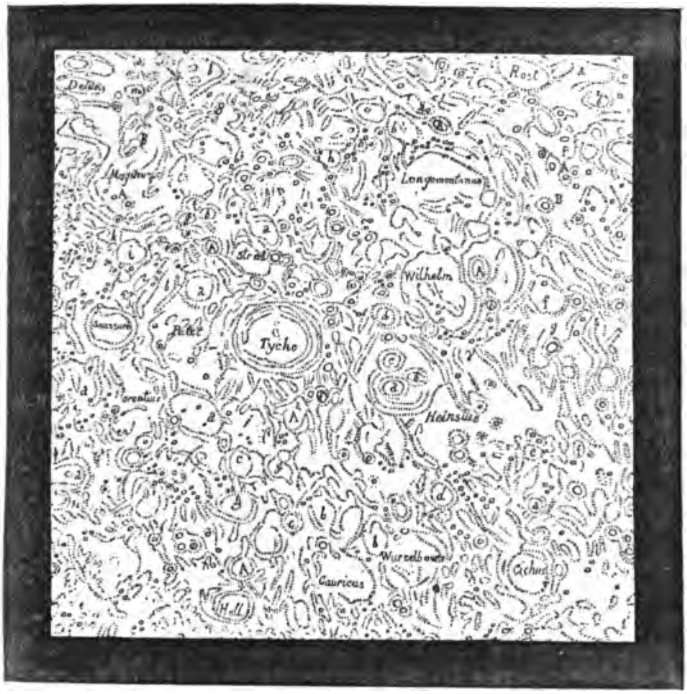
26. It has been shown that the intensity of heat on the sun's surface must be seven times as great as that of the vivid ignition of the fuel in the strongest blast furnace. This power of solar light is also proved by the facility with which the calorific rays pass through glass. Herschel found, by experiments made with an actinometer, that 81·6 per cent of the calorific rays of the sun penetrate a sheet of plate-glass 0·12 inch thick, and that 85·9 per cent. of the rays which have passed through one such plate will pass through another.†

27. One of the most difficult questions connected with the physical condition of the sun, is the discovery of the agency to which its heat is due. To the hypothesis of combustion, or any other which involves the supposition of extensive chemical change in the constituents of the surface, there are insuperable difficulties. Conjecture is all that can be offered, in the absence of all data upon which reasoning can be based. Without any chemical change, heat may be indefinitely generated either by friction or by electric currents, and each of these causes have accordingly been suggested as a possible source of solar heat and light. According to the latter hypothesis, the sun would be a great ELECTRIC LIGHT in the centre of the system.

---

* Herschel's Cape Observations, p. 434.

† Ibid., p. 133.



TELESCOPIC VIEW OF THE REGION OF THE MOON SURROUNDING THE CIRCULAR MOUNTAIN CHAIN CALLED TYCHO, MEASURING ABOUT 375 MILES NORTH AND SOUTH, AND ABOUT 200 MILES EAST AND WEST.

THE MOON.

1. Interest with which the moon is regarded, and influences with which it has been invested by the popular mind.—2. Its distance.—3. Its orbit.—4. Its magnitude.—5. Its rotation.—6. Conjunction.—7. Quadrature.—8. Opposition.—9-11. Tests of an atmosphere.—12-13. None exists on the moon.—14. No liquids.—15. No diffusion of solar light.—16. Appearance of earth seen from moon.—17. It would have belts.—18. Geographical features and its rotation would be visible through the clouds.—19. Moonlight neither warm nor cold.—20. Moon's physical condition.—21. Thickly covered with mountains.—22. Selenographical discoveries of Beer and Mädler.—23. Vast extent and diameter of the lunar mountains.—24. Circular chains.—25. Description of Tycho. — 26. Heights of lunar mountains.—27. Observations of Lord Rosse.—28. Moon not inhabited.

THE MOON.

1. Estimated merely by its magnitude, the moon is among the most inconsiderable of the bodies which compose the Solar System. It has not, as will presently appear, even that interest which must attach to a globe adapted for the habitation of organised races, analogous to those for whose dwelling the earth has been appropriated. Nevertheless it has ever been regarded by mankind with sentiments of profound and peculiar interest, and has been invested by the popular mind with various influences, affecting not only the physical condition of the globe, but also directly connected with the organised world. It has therefore been as much an object of popular superstition as of scientific observation. These circumstances are doubtless owing in some degree to its striking appearance in the firmament, to the various and rapid succession of changes of apparent form to which it is subject, and above all to its proximity to, and close alliance with our planet. We propose on the present occasion to give a general account of its motion, magnitude, and physical condition; and to explain more particularly those circumstances which lead to the conclusion that, unlike the planets, the moon presents none of the analogies to the earth which would render it at all probable or even possible that it can be a habitable world.

2. It has been ascertained, that its distance is very little less than 240000 miles; and since the semidiameter of the earth is 4000 miles, it follows that the moon's distance is about sixty semidiameters of the earth. The method of ascertaining this distance differs in nothing that is essential, from that by which a common surveyor ascertains the distance of an object on the earth which is inaccessible to him.

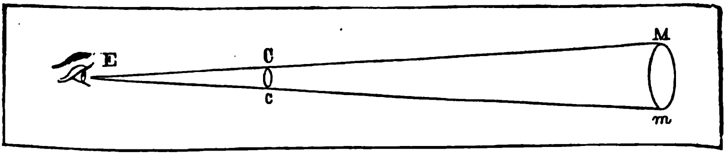
3. Now the least reflection will render it apparent that the moon must move round the earth, in a path which cannot differ much from a circle of which the earth is the centre. This follows from the fact with which every one is familiar, that its apparent magnitude is always nearly the same. It is, therefore, always at the same or nearly the same distance from the observer. The earth must consequently be placed in the centre of its path, and that path must be nearly a circle.

4. When the distance of a visible object is determined, its magnitude may easily be ascertained by comparing it with any other object of known magnitude at a known distance. Let us take, for example, a halfpenny, which measures about an inch in diameter, and let it be placed between the eye and the moon. It will be found on the first trial that the coin will appear larger than the moon; it will, in fact, completely conceal the moon from the eye, and produce what may be termed a total eclipse of that luminary. Let the coin be moved however further from the eye,

and it will apparently diminish in size as its distance is increased. Let it be removed until it becomes equal in apparent magnitude to the moon, so that it will exactly cover the moon, and neither more nor less. If its distance be then measured, it will be found to be about 120 inches, or 240 half inches. But it is known that the distance of the moon is about 240000 miles, and consequently it follows in this case, that 1000 miles in the moon's distance is exactly what half an inch is in the coin's distance. Now under the circumstances here supposed, the coin and the moon are similar objects of equal apparent magnitude. In fact the coin is another moon on a smaller *scale*, and we may use the coin to measure the moon's distance, provided we know the *scale*, exactly as we use the space upon a map of any known scale to measure a country. But it has been just stated that the *scale* is in this case half an inch to 1000 miles; since, then, the coin measures two half inches in diameter, the moon must measure 2000 miles in diameter. The moon is then a globe whose diameter is about one-fourth of that of the earth.

This may be rendered still more clear by reference to the annexed diagram (fig. 1), where E is the eye, C the coin, and M the moon. It will be evident on mere inspection, that the triangle formed by the distance EC of the coin from the eye, and the diameter Cc of the coin, is similar to the triangle formed by the distance EM of the moon from the eye and the diameter M*m* of the moon, and that consequently the proportion of EC to Cc is exactly the same as that of EM to M*m*. But as has just been stated, it is found that when Cc exactly covers the moon, and neither more nor less than covers it, EC is 120 times Cc. It follows, therefore, that EM is 120 times M*m*. But since it has been ascertained that EM is 240000 miles, that is 120 times 2000 miles, it follows that M*m* is 2000 miles.

Fig. 1.



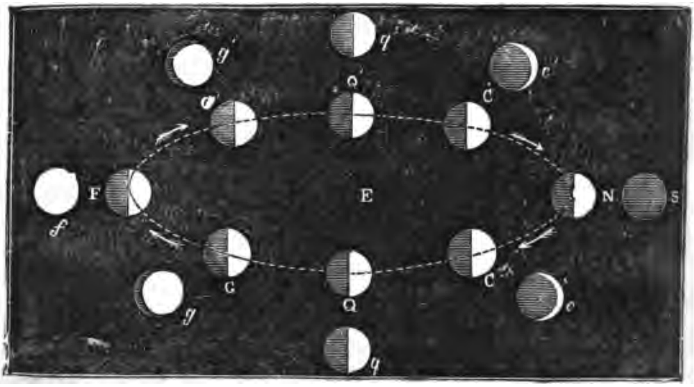
5. While the moon moves around the earth, we find by observations of its appearance, that the same hemisphere is always turned toward us. We recognise this fact by observing that the same marks always remain in the same place upon it. Now, in order that a globe which revolves around a centre should turn continually the same hemisphere toward that centre, it is necessary that

it should make one revolution upon its axis in the time it takes so to revolve. For let us suppose that, in any one position, it has the centre round which it revolves north of it, the hemisphere turned toward the centre is turned toward the north. After it makes a quarter of a revolution, the centre is to the west of it, and the hemisphere which was previously turned to the north must now be turned to the west. After it has made another quarter of a revolution the centre will be south of it, and it must be now to the south. In the same manner, after another quarter of a revolution, it must be turned to the east. As the same hemisphere is successively turned to all the points of the compass in one revolution, it is evident that the globe itself must make a revolution on its axis in that time.

It appears, then, that the rotation of the moon upon its axis being equal to that of its revolution in its orbit, is 27 days, 7 hours, and 44 minutes. The intervals of light and darkness to the inhabitants of the moon, if there were any, would then be altogether different from those provided in the planets; there would be about 13 days of continued light alternately with 13 days of continued darkness; the analogy, then, which prevails among the planets with regard to days and nights, and which forms a main argument in favour of the conclusion that they are inhabited globes like the earth, does not hold good in the case of the moon.

6. While the moon revolves round the earth, its illuminated hemisphere is always presented to the sun; it therefore takes various positions in reference to the earth. The effects of this are exhibited in the annexed fig. 2. Let E S represent the direction

Fig. 2.



of the sun, and E the earth; when the moon is at N, between the sun and the earth, its illuminated hemisphere being turned toward the sun, its dark hemisphere will be presented toward the earth; it will therefore be invisible. In this position the moon is said to be in CONJUNCTION.

When it moves to the position C, the enlightened hemisphere being still presented to the sun, a small portion of it only is turned to the earth, and it appears as a thin crescent, as represented at *c*.

7. When the moon takes the position of Q, at right angles to the sun, it is said to be in QUADRATURE: one half of the enlightened hemisphere only is then presented to the earth, and the moon appears halved as represented at *q*.

When it arrives at the position G, the greater part of the enlightened portion is turned to the earth, and it is gibbous, appearing as represented at *g*.

8. When the moon comes in OPPOSITION to the sun, as seen at F, the enlightened hemisphere is turned full toward the earth, and the moon will appear full as at *f*, unless it be obscured by the earth's shadow, which rarely happens. In the same manner it is shown that at G′ it is again gibbous; at Q′ it is halved, and at C′ it is a crescent.

If the moon or the planets be supposed to be viewed by an observer placed on the one side or the other of the general plane in which they move, they will appear to move either in the direction of the hands of a clock, or in the contrary direction, according to the side of the general plane from which they are seen. If the observer be supposed to be on the north side of that plane, their motion will be contrary to that of the hands of a clock. If he is placed on the south side of that plane, their motion will be in the direction of the hands of a clock.

In the case represented in fig. 2, and also in the astronomical diagrams in the first volume of the Museum, pp. 5, 11, &c., the observer is supposed to be placed at the south side of the general plane.

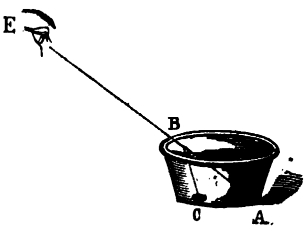
9. In order to determine whether or not the globe of the moon is surrounded with any gaseous envelope like the atmosphere of the earth, it is necessary first to consider what appearances such an appendage would present, seen at the moon's distance, and whether any such appearances are discoverable.

10. According to ordinary and popular notions, it is difficult to separate the idea of an atmosphere from the existence of clouds; yet to produce clouds something more is necessary than air. The presence of water is indispensable, and if it be assumed that no water exist, then certainly the absence of clouds is no proof of the

absence of an atmosphere. Be this as it may, however, it is certain that there are no clouds upon the moon, for if there were, we should immediately discover them, by the variable lights and shadows they would produce. If there be an atmosphere upon the moon, it is therefore one entirely unaccompanied by clouds.

11. One of the effects produced by a distant view of an atmosphere surrounding a globe, one hemisphere of which is illuminated by the sun, is, that the boundary, or line of separation between the hemisphere enlightened by the sun and the dark hemisphere, is not sudden and sharply defined, but is gradual—the light fading away by slow degrees into the darkness. It is to this effect upon the globe of the earth that twilight is owing, and as we shall see hereafter, such a gradual fading away of the sun's light is discoverable on some of the planets, upon which an atmosphere is observed. Now, if such an effect of an atmosphere were produced upon the moon, it would be perceived by the naked eye, and still more distinctly with the telescope. When the moon appears as a crescent, its concave edge is the boundary which separates the enlightened from the dark hemisphere. When it is in the quarters, the diameter of the semicircle is also that boundary. In neither of these cases, however, do we ever discover any gradual fading away of the light into the darkness; on the contrary, the boundary, through serrated and irregular, is nevertheless perfectly well defined and sudden. All these circumstances conspire to prove that there does not exist upon the moon an atmosphere capable of refracting light in any sensible degree.

Fig. 3.

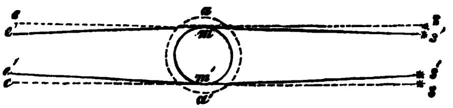


But it may be contended that an atmosphere may still exist, though too attenuated to produce a sensible twilight. Astronomers, however, have resorted to another test of a much more decisive and delicate kind, the nature of which will be understood by explaining a simple principle of optics. When a ray of light passes through a transparent medium, such as air, water, or glass, it is generally deflected from its rectilinear course, so as to form an angle. A simple and easily-executed experiment will render this intelligible. Let a visible object, such as a coin, be placed at C, in the bottom of a bucket. Let the eye be placed at E (fig. 3), so that the side of the bucket, when empty, shall just conceal the coin, and so that the nearest point to the coin visible shall be at A, in the direction of the line E B A. Let the bucket be now filled with water, and the coin will become immediately visible; the reason of which is, that the ray of light C B proceeding from the coin is bent at an angle in passing from the water into the air, and reaches the eye by the angular course C B E. Thus it appears that the coin will be visible to the eye, notwithstanding the interposition of the opaque side of the bucket.

Let us see how this principle can be applied to the case of the moon's atmosphere, if such there be.

Let *m m′* (fig. 4) represent the disk of the moon. Let *a a′* represent the atmosphere which surrounds it. Let *s m e* and *s m′ e* represent two lines touching the moon at *m* and *m′*, and proceeding towards the earth. Let *s s* be two stars seen in the direction of these lines. If the moon had no atmosphere, these stars would appear to touch the edge of the moon at *m* and *m′*, because the rays of light from them would pass directly toward the earth; but if the moon have an atmosphere, then that atmosphere will possess the property which is common to all transparent media of refracting light, and, in virtue of such property, stars in such positions as *s′ s′*, behind the edge of the moon, would be visible at the earth, for the ray *s′ m*, *s′ m′*, in passing through the atmosphere, would be bent at an angle in the direction *m e′*, and *m′ e′*, so that the stars *s′ s′* would be visible at *e′ e′*, notwithstanding the interposition of the edges of the moon.

Fig. 4.



This reasoning leads to the conclusion that as the moon moves over the face of the firmament, stars will be continually visible at its edge which are really behind it if it have an atmosphere, and the extent to which this effect will take place will be in proportion to the density of the atmosphere.

12. The magnitude and motion of the moon and the relative positions of the stars are so accurately known that nothing is more easy, certain, and precise, than the observations which may be made with the view of ascertaining whether any stars are ever seen which are sensibly behind the edge of the moon. Such observations have been made, and no such effect has ever been detected. This species of observation is susceptible of such extreme accuracy, that it is certain that if an atmosphere existed upon the

moon a thousand times less dense than our own, its presence must be detected.

13. The earth's atmosphere supports a column of 30 inches of mercury: an atmosphere 1000 times less dense would support no more than the thirtieth of an inch. It may therefore be considered as proved that the space around the surface of the moon is as exempt from an atmosphere as is the receiver of a good air-pump after that instrument has exhausted it of air to the utmost limit of its power. In fine for all practical purposes it is demonstrated that the moon has no atmosphere.

14. The same physical tests which show the non-existence of an atmosphere of air upon the moon are equally conclusive against an atmosphere of vapour. It might, therefore, be inferred that no liquids can exist on the moon's surface, since they would be subject to evaporation. Sir John Herschel, however, ingeniously suggests that the non-existence of vapour is not conclusive against evaporation. One hemisphere of the moon being exposed continuously for 328 hours to the glare of sunshine of an intensity greater than a tropical noon, because of the absence of an atmosphere and clouds to mitigate it, while the other is for an equal interval exposed to a cold far more rigorous than that which prevails on the summits of the loftiest mountains or in the polar regions, the consequence would be the immediate evaporation of all liquids which might happen to exist on the one hemisphere, and the instantaneous condensation and congelation of the vapour on the other. The vapour would, in short, be no sooner formed on the enlightened hemisphere than it would rush to the vacuum over the dark hemisphere, where it would be instantly condensed and congealed, an effect which Herschel aptly illustrates by the familiar experiment of the CRYOPHOROUS. The consequence, as he observes, of this state of things would be absolute aridity below the vertical sun, constant accretion of hoar frost in the opposite region, and perhaps a narrow zone of running waters at the borders of the enlightened hemisphere. He conjectures that this rapid alternation of evaporation and condensation may to some extent preserve an equilibrium of temperature, and mitigate the severity of both the diurnal and nocturnal conditions of the surface. He admits nevertheless that such a supposition could only be compatible with the tests of the absence of a transparent atmosphere even of vapour within extremely narrow limits; and it remains to be seen whether the general physical condition of the lunar surface as disclosed by the telescope be not more compatible with the supposition of the total absence of all liquid whatever.

It appears to have escaped the attention of those who assume the possibility of the existence of water in the liquid state on the moon, that, in the absence of an atmosphere, the temperature must necessarily be, not only far below the point of congelation of water, but even that of most other known liquids. Even within the tropics, and under the line with a vertical sun, the height of the snow line does not exceed 16000 feet, and nevertheless at that elevation, and still higher, there prevails an atmosphere capable of supporting a considerable column of mercury. At somewhat greater elevations, but still in an atmosphere of very sensible density, mercury is congealed. Analogy, therefore, justifies the inference that the total, or nearly total, absence of air upon the moon is altogether incompatible with the existence of water, or probably any other body in the liquid state, and necessarily infers a temperature altogether incompatible with the existence of organised beings in any respect analogous to those which inhabit the earth.

But another conclusive evidence of the non-existence of liquids on the moon is found in the form of its surface, which exhibits none of those well understood appearances which result from the long-continued action of water. The mountain formations with which the entire visible surface is covered are, as will presently appear, universally so abrupt, precipitous, and unchangeable, as to be utterly incompatible with the presence of liquids.

15. The general diffusion of the sun's light upon the earth is mainly due to the reflection and refraction of the atmosphere, and to the light reflected by the clouds; and without such means of diffusion the solar light would only illuminate those places into which its rays would directly penetrate. Every place not in full sunshine, or exposed to some illuminated surface, would be involved in the most pitchy darkness. The sky at noon-day would be intensely black, for the beautiful azure of our firmament in the day-time is due to the reflected colour of the air. Thus it appears that the absence of air on the moon must deprive the sun's illuminating and heating agency of nearly all its utility.

16. If the moon were inhabited, observers placed upon it would witness celestial phenomena of a singular description, differing in many respects from those presented to the inhabitants of our globe. The heavens would be perpetually serene and cloudless. The stars and planets would shine with extraordinary splendour during the long night of 328 hours. The inclination of her axis being only 5°, there would be no sensible changes of season. The year would consist of one unbroken monotony of equinox. The inhabitants of one hemisphere would never see the earth: while the inhabitants of the other would have it constantly in their firmament by day and by night, and always in the same position.

To those who inhabit the central part of the hemisphere presented to us, the earth would appear stationary in the zenith, and would never leave it, never rising nor setting, nor in any degree changing its position in relation to the zenith or horizon. To those who inhabit places intermediate between the central part of that hemisphere and those places which are at the edge of the moon's disk, the earth would appear at a fixed and invariable distance from the zenith, and also at a fixed and invariable azimuth, the distance from the zenith being everywhere equal to the distance of the observer from the middle point of the hemisphere presented to the earth. To an observer at any of the places which are at the edge of the lunar disk, the earth would appear perpetually in a fixed direction on the horizon.

The earth shone upon by the sun would appear as the moon does to us; but with a disk having an apparent diameter greater than that of the moon in the ratio of 79 to 21, and an apparent superficial magnitude about fourteen times greater, and it would consequently have a proportionately illuminating power.

Earth light at the moon would, in fine, be about fourteen times more intense than *moonlight* at the earth. The earth would go through the same phases and complete the series of them in the same period as that which regulates the succession of the lunar phases, but the corresponding phases would be separated by the interval of half a month. When the moon is *full* to the earth, the earth is *new* to the moon, and *vice versâ:* when the moon is a crescent, the earth is gibbous, and *vice versâ.*

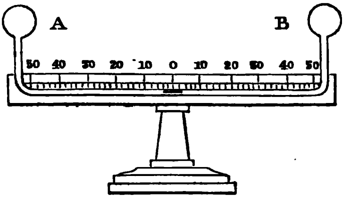
17. The features of light and shade would not, as on the moon, be all permanent and invariable. So far as they would arise from the clouds floating in the terrestrial atmosphere they would be variable. Nevertheless, their arrangement would have a certain relation to the equator, owing to the effect of the prevailing atmospheric currents parallel to the line. This cause would produce streaks of light and shade, the general direction of which would be at right angles to the earth's axis, and the appearance of which would be in all respects similar to the BELTS which are observed upon some of the planets, and which are ascribed to a like physical cause.

18. Through the openings of the clouds the permanent geographical features of the surface of the earth would be apparent, and would probably exhibit a variety of tints according to the prevailing characters of the soil, as is observed to be the case with the planet Mars even at an immensely greater distance. The rotation of the earth upon its axis would be distinctly observed and its time ascertained. The continents and seas would disappear in succession at one side and reappear at the other, passing across the disk of the earth as carried round by the diurnal rotation.

19. It has long been an object of inquiry among philosophers whether the light of the moon has any heat, but the most delicate experiments and observations have failed to detect this property in it. A thermometer of extreme sensibility, called a differential thermometer, was the instrument applied to this inquiry.

This instrument consists of two glass bulbs, A and B (fig. 5), connected by a rectangular glass tube. In the horizontal part of the tube a small quantity of coloured liquid (sulphuric acid, for example) is placed. Atmospheric air is contained in the bulbs and tube, separated into two parts by the liquid. The instrument is so adjusted that, when the drop of liquid is at the middle of the horizontal tube, the air in the bulbs has the same pressure; and having equal volumes, the quantities at each side of the liquid are necessarily equal. If the bulbs be affected by different temperatures, the liquid will be pressed from that side at which the temperature is greatest, and the extent of its departure from the zero or middle is indicated by the scale. This thermometer is sometimes varied in its form and arrangement, but the principle remains the same. Its extreme sensitiveness, in virtue of which it indicates changes of temperature too minute to be observed by common thermometers, renders it extremely valuable as an instrument of scientific research. By this instrument, changes of temperature not exceeding the 6000th part of a degree are rendered sensible.

Fig. 5.



The light of the moon was collected into the focus of a concave mirror of such magnitude as would have been sufficient, if exposed to the sun's light, to evaporate gold or platinum. The bulb of the differential thermometer was placed in its focus, so as to receive upon it the concentrated rays of the moon. Yet no sensible effect was produced upon the thermometer. We must therefore conclude that the light of the moon does not possess the calorific property in any sensible degree.

This result will create less surprise when the comparative intensity of sunlight and moonlight are considered. It may be assumed, without sensible error, that the intensity of the sun's light on the surface of the moon and on the earth is the same; it follows from this, that supposing no light whatever to be absorbed by the moon, but the entire light of the sun to be reflected from its surface undiminished, the intensity of moonlight at the earth would bear to the intensity of sunlight the same proportion as the magnitude of the moon bears to the magnitude of the entire firmament, that is, the proportion very nearly of 1 to 300000; but there is no reflecting surface, however perfect, which does not absorb the light incident upon it in a very considerable degree, and the rugged surface of the moon must be a most imperfect reflector. It may then be considered as demonstrated that the intensity of moonlight is much more than 300000 times more feeble than that of sunlight. We shall not, then, be surprised at the absence of its heating power.

But if the rays of the moon be not warm, the vulgar impression that they are cold is equally erroneous. We have seen that they produce no effect either way on the thermometer.

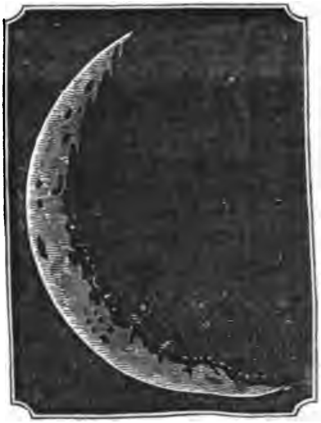
20. Curiosity will doubtless be awakened in a very lively manner regarding the physical condition of our moon: what part has the Maker of the solar system destined this body to play in the economy of His creation? Is it a globe teeming with life and organisation like the earth? Is that orb, which rolls in silent majesty through the midnight firmament, the abode of life and intelligence? The beauty of her appearance naturally leads the mind to conjectures of this kind. Yet the circumstances which I have unfolded regarding the total absence of air and water appear to exclude the possibility of any such supposition. How, may it be asked, can it be conceived that a globe can have upon it an organised world which is destitute of fluid matter in every form? How can growth, which implies gradual change, increase, and diminution, and all the various effects in which fluidity is an agent, go on there? How can they proceed upon such a solid, arid, unchangeable, crude mass? Let it be remembered what a multitude of purposes in our natural and social economy are subserved by the combination of the water and the atmosphere of our globe. None of these purposes can be fulfilled upon the moon. Perhaps, however, our notions on such questions may be cleared up to some extent by a careful examination of the facts that scientific research has collected respecting the physical condition of the surface of our satellite.

21. If, when the moon is a crescent, we examine with a telescope, even of moderate power, the concave boundary which is that part of the lunar surface where the enlightened hemisphere

ends and the dark hemisphere begins, we shall find that it is not an even and regular curve, which it undoubtedly would be if the surface of the globe of the moon were smooth and regular, or nearly so. If, for example, the lunar surface resembled in its general characteristics that of our globe; granting the total absence of water, and that the entire surface is land, but that land had the general characteristics of the continents of the globe of the earth; then I say, that the inner boundary of the lunar crescent would still be a regular curve, broken or interrupted only at particular points. Where great mountain ranges, like those of the Alps, the Andes, or the Himalaya, might chance to cross it, these lofty peaks would project vastly-elongated shadows along the adjacent plain; for it will be remembered that, being situated at the moment in question at the boundary of the enlightened and darkened hemispheres, the shadows would be those of evening and morning; which are prodigiously longer than the objects themselves. The effects of these would be to cause gaps or irregularities in the general outline of the inner boundary of the crescent; with these rare exceptions, the inner boundary of the crescent produced by a globe like the earth would be an even and regular curve.

Such, however, is not the case with the inner boundary of the lunar crescent, even when viewed by the naked eye, and still less so when magnified by a telescope. It is found, on the contrary, rugged and serrated, and brilliantly illuminated points are seen in the dark parts at some distance from it, while dark shadows of considerable length appear to break into the illuminated surface. The inequalities thus apparent indicate singular characteristics of the surface. The bright points seen within the dark hemisphere are the peaks of lofty mountains tinged with the sun's light. They are in the condition with which all travellers in Alpine countries are familiar; after the sun has set, and darkness has set in over the valleys at the foot of the chain, the sun still continues to illuminate the peaks above. The sketch (fig. 6), of the lunar crescent, will illustrate these observations.

Fig. 6.



22. The visible hemisphere of our satellite has, within the last quarter of a century, been subjected to the most rigorous examination which unwearied industry, aided by the vast improvement which has been effected in the instruments of telescopic observation, rendered possible; and it is no exaggeration to state that we now possess a chart of that hemisphere, which in accuracy of detail far exceeds any similar representation of the earth's surface.

Among the selenographical observers, the Prussian astronomers, MM. Beer and Mädler, stand pre-eminent. Their descriptive work, entitled "Der Monde," contains the most complete collection of observations on the physical condition of our satellite, and the chart, measuring 37 inches in diameter, exhibits the most complete representation of the lunar surface extant. Besides this great work, a selenographic chart was produced by Mr. Russel, from observations made with a seven-foot reflector, a similar delineation by Lohrmann, and, in fine, a very complete model in relief of the visible hemisphere by Madame Witte, a Hanoverian lady.

23. The surface of the visible hemisphere is thickly covered with mountainous masses and ranges of various forms, magnitudes, and heights, in which, however, the prevalence of a circular or crater-like form is conspicuous. The various tints of white and gray which mark the lineaments observed upon the disk arise partly from the different reflecting powers of the matter composing different parts of the lunar surface, and partly from the different angles at which the rays of the solar light are incident upon them. The more intensely white parts are mountains of various magnitude and form, whose height, relatively to the moon's magnitude, greatly exceeds that of the most stupendous terrestrial eminences; and there are many characterised by an abruptness and steepness which sometimes assume the position of a vast vertical wall, altogether without example upon the earth. These are generally disposed in broad masses, lying in close contiguity, and intersected with vast and deep valleys, gullies, and abysses, none of which, however, have any of the characters which betray the agency of water.

24. There are circular areas, varying from 40 to 120 miles in diameter, enclosed by a ring of mountain ridges, mostly continuous, but in some cases intersected at one or more points by vast ravines. The enclosed area is generally a plain on which mountains of less height are often scattered. The surrounding circular ridge also throws out spurs, both externally and internally, but the latter are generally shorter than the former. In some cases, however, internal spurs, which are diametrically opposed, unite

in the middle so as to cut in two the enclosed plain. In some rare cases the enclosed plain is uninterrupted by mountains, and it is almost invariably depressed below the general level of the surrounding land. A few instances are presented of the enclosed plain being convex.

The mountainous circle enclosing these vast areas is seldom a single ridge. It consists more generally of several concentric ridges, one of which, however, always dominates over the rest, and exhibits an unequal summit, broken by stupendous peaks, which here and there shoot up from it to vast heights. Occasionally it is also interrupted by smaller mountains of the circular form.

25. The most remarkable of the class of lunar mountains, called ring mountains, is that called TYCHO. This object is distinguishable without a telescope on the lunar disk when full; but, owing to the multitude of other features which become apparent around it in the phases, it can then be only distinguished by a perfect knowledge of its position, and with a good telescope. The enclosed area, which is very nearly circular, is 47 miles in diameter, and the inside of the enclosing ridge has the steepness of a wall. Its height above the level of the enclosed plain is 16000 feet, and above that of the external regions 12000 feet. There is a central mountain, having the height 4700 feet, besides a few lesser hills within the enclosure.

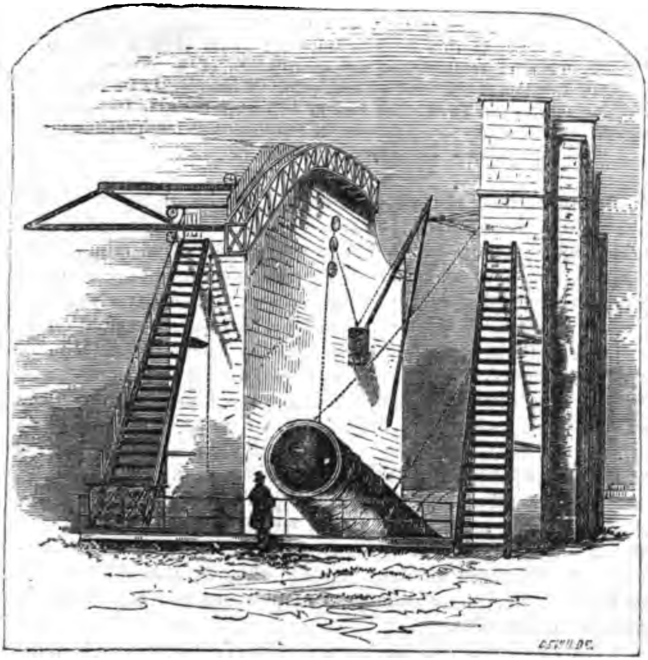
This region of the moon is represented in the engraving at the head of this tract, copied and reduced from the chart of MM. Beer and Mädler. The volcanic character observed in the mountain formations loses much of its analogy to like formations on the earth's surface when higher magnifying powers enable us to examine the forms of what appear to be craters, and to compare their dimensions with even the most extensive terrestrial craters. Numerous examples may be produced to illustrate this. Tycho, which, viewed under a moderate magnifying power, appears to possess in so eminent a degree the volcanic character, is, as has been stated, a circular chain enclosing an area of 47 miles in diameter. Gassendi, another system of like form, and of still more stupendous dimensions, as seen with high magnifying powers, consists of two enormous circular chains of mountains, the lesser, which lies to the north, measuring 16½ miles in diameter, and the greater, lying to the south, enclosing an area 60 miles in diameter. The area enclosed by the former is therefore 214, and by the latter 2827 square miles. The height of the lesser chain is about 10000 feet, while that of the greater varies from 3500 to 5000 feet. The vast area thus enclosed by the greater chain includes, at or near its centre, a principal central mountain, having eight peaks and an height of 2000 feet, while scattered over the surrounding enclosure upwards of a hundred mountains of less considerable elevation have been counted.

It is easy to see how little analogy to a terrestrial volcanic crater is presented by these characters.

26. In the work of Beer and Mädler a table of the heights of above 1000 mountains is given, several of which attain to an elevation of 23000 feet, equal to that of the highest summits of terrestrial mountains, while the diameter of the moon is little more than a fourth of that of the earth.

27. By means of the great reflecting telescope of Lord Rosse, the flat bottom of the crater called Albategnius is distinctly seen to be strewed with blocks, not visible with less powerful instruments; while the exterior of another (Aristillus) is intersected with deep gullies radiating from its centre.

28. In fine, the entire geographical character of the moon, thus ascertained by long-continued and exact telescopic surveys, leads to the conclusion that no analogy exists between it and the earth which would confer any probability on the conjecture that it fulfils the same purposes in the economy of the Universe, and we must infer that whatever be its uses in the solar system, or in the general purposes of creation, it is not a world inhabited by organised races, such as those to which the earth is appropriated.



THE GREAT ROSSE TELESCOPE.

THE PLANETS:

ARE THEY INHABITED WORLDS?

CHAPTER I.

1.—Aspect of the firmament.—2. Direct evidence on this question not obtained by the telescope.—3. Telescope diminishes distance.—4. Evidence from analogy extremely cogent.—5. Consideration of the terrestrial planets.—6. Circumstances which render the earth habitable.—7. Like circumstances to be looked for in the planets.—8. Similarity of position and motion of terrestrial planets.—9. Uniformly supplied with light and heat.—10. Objection of inequality of distance answered.—11. By the effect of atmosphere.—12. Different degrees of light on the planets.—13. Structure of the eye.—14. Its adaptation to different distances.—15. Adaptation of strength of

organised creatures to their weight.—16. Adaptation of the rotation of the earth to this organisation.—17. Floral clock of Linnæus.—18. Time of rotation not the consequence of a physical law.—19. Rotation of the other planets.—20. Of Mars.—21. Of Venus and Mercury.—22. Their close analogy to the earth.—23. Inclination of the earth's axis.—24. Produces the seasons.—25. Like provision in the other planets—26. The Atmosphere.

1. When we walk abroad on a clear starlight night, and direct our view to the aspect of the heavens, there are certain reflections which will present themselves to every meditative mind. Are those shining orbs, which in such countless numbers decorate the firmament, peopled with creatures endowed like ourselves with reason to discover, with sense to love, and with imagination to expand to their boundless perfection the attributes ot Him of "whose fingers the heavens are the work?" Has He, who "made man lower than the angels to crown him" with the glory of discovering that light in which He has "decked himself as with a garment," also made other creatures with like powers and like destinies, with dominion over the works of His hands, and having all things put in subjection under their feet? And are those resplendent globes which roll in silent majesty through the measureless abysses of space, the dwellings of such beings? These are inquiries against which neither the urgency of business nor the allurements of pleasure can block up the avenues of the mind.

2. Those whose information on topics of this nature is most superficial, would be prompted to look immediately for direct evidence on these questions; and consequently to appeal to the telescope. Such an appeal would, however, be fruitless. Vast as are the powers of that instrument it still falls infinitely short of the ability to give direct evidence on such inquiries. What will a telescope do for us in the examination of any of the heavenly bodies, or indeed of any distant object? It will accomplish this, and nothing more; it will enable us to behold it, as we should see it at a lesser distance. But, strictly speaking, it cannot accomplish even this: for to suppose it did, would be to ascribe to it all the admirable optical perfection of the eye; for that instrument, however nearly it approaches the organ of vision, is still deficient in some of the qualities which have been conferred upon the eye by its Maker.

3. Let us, however, assume that we resort to the use of a telescope having such a magnifying power, for example, as a thousand: what would such an instrument do for us? It would in fact place us a thousand times nearer to the object that we are desirous to examine, and thus enable us to see it as we should at

that diminished distance without a telescope. Such is the extent of the aid which we should derive from the instrument. Now, let us see what this aid would effect. Take, for example, the case of the moon, the nearest body in the universe to the earth. The distance of that object is about 240,000 miles; the telescope would then place us at 240 miles from it. Could we at the distance of 240 miles distinctly, or even indistinctly, see a man, a horse, an elephant, or any other natural object? Could we discern any artificial structure? Assuredly not! But take the case of one of the planets. When Mars is nearest to the earth, its distance is about 50,000000 of miles. Such a telescope would place us at a distance of 50,000 miles from it. What object could we expect to see at 50,000 miles' distance? The planet Venus, when nearest the earth, is at a distance something less than 30,000000 of miles, but at that distance her dark hemisphere is turned towards us; and when a considerable portion of her enlightened hemisphere is visible, her distance is not less than that of Mars. All the other planets, when nearest to the earth, are at much greater distances. As the stars lie infinitely more remote than the most remote planet, it is needless here to add anything respecting them.

4. It is plain, that the telescope cannot afford any direct evidence on the question whether the planets, like the earth, are inhabited globes. Yet, although science has not given direct answers to these questions, it has supplied a body of circumstantial evidence bearing upon them of an extremely interesting nature. Modern discovery has collected together a mass of facts connected with the position and motions, the physical character and conditions, and the parts played in the solar system by the several globes of which that system is composed, which forms a body of analogies bearing on this inquiry, even more cogent and convincing than the proofs on the strength of which we daily dispose of the property and lives of our fellow-citizens, and hazard our own.

5. We shall first consider this interesting question so far as relates to the group of planets, which from several striking analogies which they bear to our own, have been called the terrestrial planets. These planets, in number three, and by name Mercury, Venus, and Mars, revolve with the earth around the sun, at distances from that luminary less in a great proportion than the other members of the solar system. We shall next extend the same inquiries to the other bodies composing that system, as well as to those which are distributed through the more distant regions of the universe.

6. In considering the earth as a dwelling-place suited to man and to the creatures which it has pleased his Maker to place in

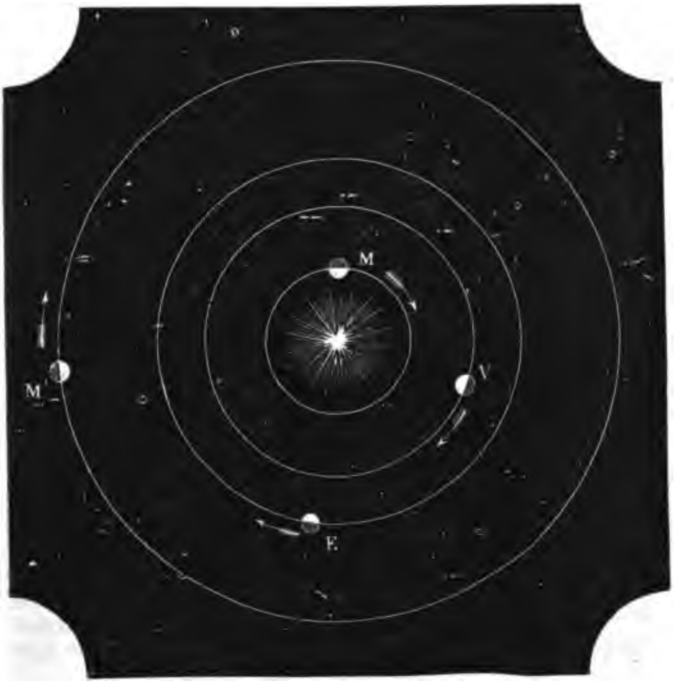
subjection to him, there is a mutual fitness and adaptation observable among a multitude of arrangements which cannot be traced to, and which indeed obviously cannot arise from, any general mechanical law by which the motions and changes of mere material masses are governed. It is in these conveniences and luxuries with which our dwelling has been so considerately furnished, that we see the beneficent intentions of its Creator more immediately manifested, than by any great physical or mechanical laws, however imposing or important. If—having a due knowledge of our natural necessities—of our appetites and passions—of our susceptibilities of pleasure and pain—in fine, of our physical organisation—we were for the first time introduced to this glorious earth with its balmy atmosphere—its pure and translucent waters—the life and beauty of its animal and vegetable kingdoms—with its attraction upon the matter of our own bodies just sufficient to give them the requisite stability, and yet not so great as to deprive them of the power of free and rapid motion—with its intervals of light and darkness, giving an alternation of labour and rest nicely corresponding wlth our muscular powers—with its grateful succession of seasons and its moderate variations of temperature so justly suited to our organisation: with all this fitness before us, could we hesitate to infer that such a place must have been provided expressly for our habitation?

7. If, then, the discoveries ot science disclose to us in each planet, which, like our own, rolls in regulated periods round the sun, provisions in all respects similar—if they are proved to be similarly built, ventilated, warmed, illuminated, and furnished—supplied with the same alternations of light and darkness by the same expedient—with the same pleasant succession of seasons—the same diversity of climates—the same agreeable distribution of land and water—can we doubt that such structures have been provided as the abodes of beings in all respects resembling ourselves? The strong presumption raised by such analogies is converted into a moral certainty, when it is shown from arguments of irresistible force that such bodies are the creation of the same Hand that raised the round world and launched it into space. Such, then, is the nature of the evidence which science offers on this interesting question. Let us endeavour to strip it of such technical forms of language and reasoning as are intelligible only to the scientific, and to present it so as to be easily and agreeably comprehended.

8. If we look at a plan of the solar system, but more especially of that part of it to which we desire now more particularly to call the attention of the reader, the first glance will impress us with

the idea that the earth is only an individual of a class of worlds of which the three other planets are members. Look at the annexed plan, fig. 1, which represents the relative positions of these planets in their courses round the sun. The position of Mercury is represented at M, that of Venus at V, that of the Earth at E, and that of Mars at M'. The circles represent the paths in which they severally move in going round the sun, which is represented radiating its light and heat from the common centre.

Fig. 1.



These four bodies are globular in their forms, and not extremely different in their magnitudes. They move round the sun as a common centre in circular orbits, as indicated in the plan, and nearly in the same plane.

Now the impression is irresistible that these four globes are bodies of the same class; but let us see the purposes in the economy of nature which are fulfilled by this common character given to the motions of these planets and the position of the sun.

9. We find, upon considering the qualities of organised bodies, and especially of the species of the animals and vegetables upon the earth, that the maintenance of their physical well-being is essentially dependent on the uniformity and regularity with which they are supplied with the two great physical principles of light and heat. Should these, or either of them, be subject to any extreme variations, such vicissitudes would be incompatible with the organisation of the species. There is a cold on one hand and a heat on the other, under which no organised body could continue to exist, and there are still narrower limits within which it is necessary to confine the temperatures they are exposed to, in order to secure the perfection of their physical health. There are also degrees of light, the intensity of which would be incompatible with the continued perfection of the organs of vision.

Seeing then how essential to the well-being of the creatures that people this globe an uniform supply of light and warmth is, we are naturally led to examine the expedient by which this necessary provision has been secured to them. If we had a fire in our neighbourhood which at once supplied light and heat, and that circumstances obliged us continually to shift our position in relation to it, how should we move so as to receive an uniform degree of illumination and warmth from it? Could we move in any other path than that of a circle around the fire as a centre, keeping thereby always at the same distance from it? Now this is exactly the path in which the earth moves, as represented in the plan; and we find that the three other planets severally also move in circles, each keeping continually at the same distance from the common fountain of light and heat.*

10. Since this motion in the case of the earth is an expedient whereby an important end is attained, analogy justifies the conclusion that it is to be regarded likewise as the expedient for the attainment of a similar end in each of the planets. But it will probably be said that the planets are at different distances from the sun: therefore, that although it must be admitted that each planet (considered *per se*) is supplied uniformly with light

---

* The paths of the planets in moving round the sun when submitted to extremely accurate examination prove to be oval in their form, but their departure from the circular form is so very minute, that if such an orbit were described in its proper proportions on paper, it would be indistinguishable from a circle. For all the purposes of the argument here advanced, the paths of the planets may, therefore, be taken to be concentric circles with the sun in the common centre.

and warmth by this circular motion; yet the intensity of these principles to which they severally are exposed, comparing one with another, is so extremely different as to destroy all analogy between them.

11. In answer to this, we are, however, to consider that the influence of light and heat upon a planet does not depend solely on its distance from the sun. The heat, as is well known, produced by the solar rays, depends on the density of the air which surrounds the objects affected by it. Thus we find the temperature, at great elevations in our own atmosphere, considerably lower than at the mean surface of our globe; because at these elevations the air becomes so thin as to be incapable of collecting and retaining the sun's heat. We can, therefore, easily imagine, provided the existence of planetary atmospheres be conceded, that their densities have been so regulated, that the nearest planets to the sun, which receive the greatest intensity of its rays, may not, after all, be subject to a greater temperature than the most remote ones, which are exposed to the least intensity of its rays: just as we find that the temperature of the summits of lofty mountains at the tropics is as low as the temperature of some of the polar latitudes. It is plain, then, how the effects of the various distances of the planet from the sun may be equalised and compensated. The means of accomplishing this are provided in the form of atmospheres, as we shall presently see.

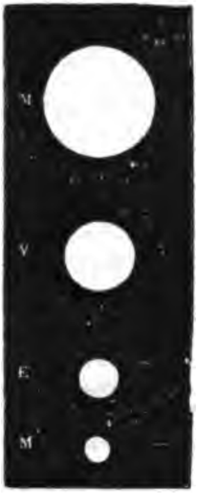
12. But let us turn to the consideration of the solar light. The intensity of the sun's light varies with his distance exactly in the same proportion as that of his heat; and the brightness of the day in each of the planets would be in the exact proportion of the apparent magnitudes of the sun as seen from them severally. Now, it is evident, that as we approach any object, its visual magnitude increases, and, as we recede from it, its visual magnitude diminishes. A balloon seen at the place from which it makes its ascent appears of vast dimensions. Seen at a great height in the air, it is diminished to a mere spot. Looking from the summit of the cliffs of Dover, Edgar says to Kent—

> Half way down
> Hangs one that gathers samphire; dreadful trade!
> Methinks, he seems no bigger than his head:
> The fishermen, that walk upon the beach,
> Appear like mice; and yon' tall anchoring bark,
> Diminish'd to her cock; her cock, a buoy
> Almost too small for sight.

Knowing the relative distances of Mercury, Venus, the Earth, and Mars from the sun, nothing is more easy than to ascertain by calculation the relative apparent magnitudes of the sun, as seen from them severally; since the apparent diameter must decrease in exactly the same proportion as the distance from the sun increases, and *vice versâ*. In this way we find that the sun, as seen from the four planets, has the relative magnitudes shown in fig. 2, where E being taken to represent the disc of the sun, as seen from the Earth, M will be its disc as seen from Mercury, V, as seen from Venus, and M′, as seen from Mars.

The brightness of the sun's light at Mercury will be greater than at the Earth, in the same proportion, as M is greater than E, and its light at Mars will be less bright than at the Earth, in the same ratio as that in which M′ is less than E. It might, therefore, be concluded that the light at Mars would be too feeble, and the light at Mercury too intense for vision.

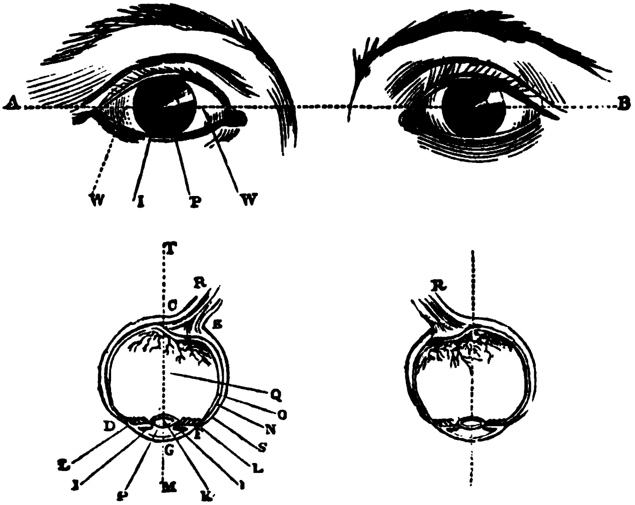
Fig. 2.



13. A slight consideration of the structure and functions of the eye will, however, demonstrate how easily such difficulties may be removed. The perception of light which any creature possessing that organ acquires, depends (*cæteris paribus*) upon the magnitude of the circular aperture or *foramen*, in front of the eye, called the *pupil*, which has, externally, the appearance of a circular black spot; but which is, in reality, a circular hole through which the light is admitted to the interior of the chamber of vision, there to affect the membranous coating which transmits its influence to the brain and causes the sensation.

This will be better understood by reference to the annexed figures, 3 and 4, the former representing the external form and appearance of the eye, and the latter a section of the eye-ball, made in a horizontal plane through the dotted line A B. The line P (fig. 3), points to the pupil, I to the iris, a coloured ring surrounding the pupil; and W to the white of the eye. In fig. 4, P points to the pupil, I to the iris, and N and O to a membranous coat full of nerves and blood-vessels which lines the inside of the eye-ball. The light, entering from M G through the pupil, and passing through the internal humours of the eye, which are perfectly transparent, strikes on that membranous coating and acts upon it in such a manner as to produce a perception. The apparent brightness of the light will obviously depend on the quantity which enters the eye through the pupil, and the sensitiveness of the membranous coating on which it acts.

Fig. 3.



14. If, then, the pupils of eyes on Venus or Mercury were smaller, and those on Mars larger, in the same proportion as E is smaller than V and M (fig. 2), and larger than M′, the membranous coating having the same sensibility, the apparent brightness of the solar light would be the same to all of them. Or supposing the pupils of the eyes to have the same magnitude, a like effect would be produced by imparting to the membranous coatings different degrees of sensibility, the sensibility on Venus and Mercury being less, and on Mars greater, than those of the eyes upon the Earth.

15. In considering the powers of locomotion and strength conferred upon animals on the earth, we find that they have certain limitations; that animals are capable of exercising these powers for certain periods, varying, it is true, among individuals, but still in the main comprised within certain narrow limits. We find that after the lapse of certain intervals, bodily repose is wanted. But besides the disposition to activity and locomotion and the alternate want of rest, animals in general have also

other wants and capabilities of enjoyment which are periodical. Thus they are capable of wakefulness for certain periods, after which recurs the physical want of sleep. Now upon a general survey of the creation, it is found that the average period which must regulate the intervals of labour and rest, of wakefulness and sleep, corresponds in the main with that which regulates the alternations of light and darkness.

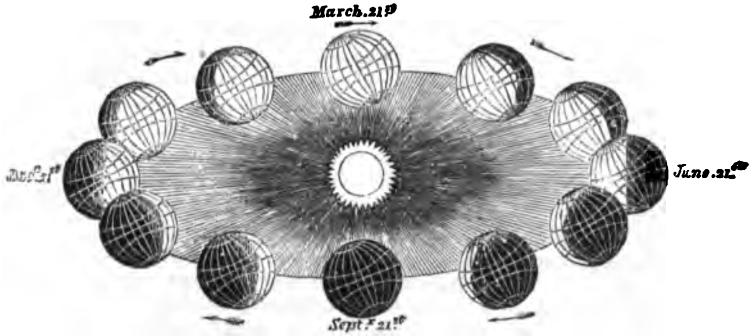
In the vegetable kingdom we find prevailing also periodical functions, certainly not so obvious and apparent, but not on that account the less interesting, which are ascertained to have the same close alliance with the period that regulates the returns of light and darkness. Plants undergo certain changes and suffer certain effects, in the presence of solar light, which are different from, and in some respects contrary to, those which they undergo in its absence. These changes are essential to the vegetable health of the creature; without them the tribes of plants would be extinct.

16. The duration of these operations is just as essential as their alternations. Light must be present a certain time, and neither more nor less; and its absence must be equally regulated by limits, otherwise the plant must perish. There is, then, it is evident, an essential relation between the functions and qualities of the vegetable kingdom—between the power of activity, the susceptibility of enjoyment and the physical wants of animals, and the periods which separate light from darkness; but what are those periods? What is the mechanical expedient to which He has resorted to accomplish His inscrutable purposes, who divided the light from the darkness, and "*saw that it was good*"? Nothing can be more simple. Nothing can be more beautiful. Nothing can be more admirably perfect. While the globe of the earth makes its annual course round the sun, it has at the same time a spinning motion, on a certain diameter, as an axis, in virtue of which it successively exposes all parts of its surface to the light and warmth of the sun. Each complete rotation is accomplished in the interval which we call twenty-four hours. All points on our earth are alternately exposed to and withdrawn from the solar light. The earth, in its annual movement round the sun, is represented in Fig. 5. It will be seen that one hemisphere is shone upon by the sun while the other is dark. But as the globe revolves on its axis once in twenty-four hours, each side is successively exposed to the sun's light and heat, for average intervals of twelve hours.

The culinary process of turning meat by a string or on a spit, successively exposing every side to the heat of the fire, is a homely illustration of this expedient.

Now when we reflect on the correspondence between these intervals and the indispensable wants of all organised creatures, can we for a moment doubt that the earth was made to turn upon its axis in that particular time rather than any other, because it was more conducive than otherwise to the well-being of the countless myriads of species, the production of the Divine hand, for whose enjoyment the earth was made? Had the time of rotation been materially less than it is, our periods of activity and labour would be too short to prepare us for the return of darkness, and had the time of rotation been greater, we should have needed rest before the return of the natural epoch designed for it. As it is, the natural vicissitudes are nicely adapted to our wants; and yet our organisation is in no way connected physically with the rotation of the earth, by any relation of the nature of cause and effect, and to suppose such an adaptation fortuitous, would be an outrage upon all principles of probability. This mutual fitness is, then, another of the many proofs which offer themselves that the earth as a dwelling, and man as a dweller, have been expressly designed each for the other.

Fig. 5.



17. Many examples may be given of this correspondence between the time of rotation of the earth upon its axis and the periodical functions of the organised world. Linnæus proposed the use of what he termed a *floral clock*, which was to consist of plants which opened and closed their blossoms at particular hours of the day. Thus, the day-lily opens at five in the morning, the common dandelion at six, the hawk-weed at seven, the marigold at nine, and so on; the closing of the blossoms marking

corresponding hours in the afternoon. Nor can this be regarded as a specific effect of light upon the plants, for when the flowers are introduced into a dark chamber they are found to open and close their blossoms at the same times.

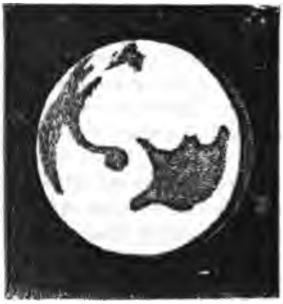
18. The necessity of maintaining a correspondence between the intervals of activity and repose, the taking of food, &c., and the period of light and darkness, was shown in the case of voyages made to the north pole, where navigators attained those latitudes in which the sun never rises for several weeks, in which cases it was found necessary to make the crews of the ships adhere to the habit of retiring at nine o'clock and rising at a quarter before six. Under these circumstances they enjoyed a state of salubrity very remarkable, notwithstanding the trying severity of climate to which they were exposed.

As an example of creative beneficence the rotation of the earth in twenty-four hours would lose none of its force if that particular period, like the time of its revolution round the sun, were a necessary consequence of an established physical law. It is interesting, nevertheless, to observe that such is not the case. No law of matter would have prevented the earth from receiving any other rate of rotation more or less rapid. It might have made a single rotation a month, in which case the average alternations of day and night would have been a fortnight, or it might have made a single rotation in an hour, in which case the alternations would have been thirty minutes. Such conditions though physically admissible, would be obviously incompatible with the continuance of the organised world. We are, then, to regard this period of diurnal rotation of the earth and its admirable adaptation to the wants and well-being of the creatures which inhabit it, not as the result of any law of physics, but as a provision directly emanating from divine beneficence, and as an example of the infinite skill of the hand which at the moment of its creation launched the earth into space.

19. Seeing then,—that the expedient of making the globe of the earth turn upon its axis in twenty-four hours is one productive of such multifarious benefits, and so intimately related to the organised species of our globe, that were it to turn otherwise than it does, in a greater or less time, an entire derangement of the animal or vegetable economy would ensue,—it becomes an interesting question to ascertain whether the other planets are provided with a similar expedient; and if so, to what extent the application of such expedient corresponds with the case of the earth. We accordingly find that all the planets without exception have a motion of rotation on certain diameters as

an axis, while they make their periodical revolutions round the sun, and that the diameter on which they so rotate has been selected in such a manner as to secure to each of them regular alternations of light and darkness in every part of their surfaces; in fact, they, like the earth, have days and nights. But are those days and nights regulated by the same intervals as ours? for that is an important question; such intervals being as we have shown, a key to the organisations and functions of the creatures upon them respectively.

Fig. 6.



20. When a telescope of adequate power is directed to the planet Mars, it is observed that the surface of his disc is diversified by certain features of light and shade like that of the moon. Some of these lights and shadows are shifting and variable, but most of them are permanent and unalterable. In fig. 6, a view of these permanent lineaments as they are presented in a certain aspect is given, taken from a telescopic drawing of the planet, made by M. Madler, the celebrated Prussian observer.

Now if these outlines of light and shade be watched for some hours, they will be observed to be carried slowly from one side of the disc to the other. Each of these will in succession disappear at one side, others coming into view at the other, and after an interval of about twelve hours, the marks which disappeared at one side will be found to re-appear at the other, and this goes on continually.

It is scarcely necessary to say that those are the effects of the rotation of the planet on its axis, and since the same features after disappearing at one side always return to the same precise position on the disc after an interval of 24h. 37m. 22s., it follows that the planet turns upon its axis in that interval.

21. By means very nearly similar strong reasons have been found for concluding that the globe of Venus turns on its axis in 23h. 21m. 21s., and that of Mercury in 24h. 5m.

22. Thus it appears that these three planets, not only have days and nights, but that these days and nights are for all practical purposes similar to those of the Earth. They are regulated by the same average duration; and He that gave them those alternations has seen it good to "divide the light from the darkness" after the same fashion.

If, then, the duration of our days and nights be evidently regulated with a view to the accommodation and well-being of the organised creatures to which the earth has been appropriated, we are surely warranted by all analogy in concluding that the adaptation of the same expedients in the planets Mercury, Venus, and Mars, has been directed to the same beneficent purposes, and that the creatures upon them, as upon the earth, are so organised as to require the same intervals of labour and rest, of activity and repose, of wakefulness and sleep.

23. In considering the expedient by which days and nights are secured to the planets, it is interesting to contemplate the particular position of the diameters on which they have been made to turn. There are a great variety of different diameters upon which the earth might have spun while it revolves round the sun. It might, for example, have turned on a diameter at right angles to its annual orbit. If such had been the case we should have had equal days and nights throughout the entire year, and at every part of the earth.

If its axis, as it might have been, had been in the plane of its annual orbit, the sun would have been constantly above the horizon for an interval of several weeks in summer, and constantly below it for a like interval in winter. The duration of these intervals of incessant light and incessant darkness would have varied in different parts of the earth, increasing with the latitude. No diurnal alternations of light and darkness would take place except for a short interval before and after the equinoxes.

It is not necessary to enlarge upon the consequences of such an arrangement, to render it apparent that they would be utterly incompatible with the well-being, and perhaps even with the maintenance, of the organised world.

In the first of the cases here supposed, we should have been deprived of the seasons and of the means of maintaining a convenient chronology, and in both cases we should be stripped of many of the benefits and utilities arising from the present arrangement.

24. But, between these extreme possible positions of the axis of rotation, there are an infinite variety which would have been nearly as unsuitable. Had the axis leaned down nearly to the ecliptic, consequences would have ensued almost as fatal as those which a position in the plane of the ecliptic would have inferred. We find, however, in fact, that a position has been given to this axis slightly inclined from the perpendicular, as represented in fig. 5. In virtue of this inclination the northern hemisphere leans toward the sun during one half of the year, and

the southern hemisphere during the other. We enjoy by this expedient the grateful succession of seasons; it is thus that spring, summer, autumn, and winter, follow each other with pleasant variety, marking in their progress by obvious phenomena the course of time. Yet this inclination or stooping of the axis is so regulated that the extremes of the seasons are confined within such moderate limits as are necessary and conducive to the physical well-being of the numerous tribes which people the earth.

It is true that this succession of seasons was not indispensably necessary to the continuance of the races that inhabit the earth, for had the axis been perpendicular to the orbit so as to render days and nights perpetually and everywhere equal, the organised world would still have continued to exist though subject to certain modifications.

25. Now, on observing the position of the axis on which Mars revolves, we find that it is inclined to the plane of the orbit of that planet, at an angle of 28° 27′, not very different from that at which the axis of the Earth is inclined to the ecliptic. The seasons and climates of Mars are therefore similar to those of the Earth.

Observation has not yet determined the position of the axes of rotation of Venus and Mercury, but it is probably not materially different from that of Mars and the Earth.

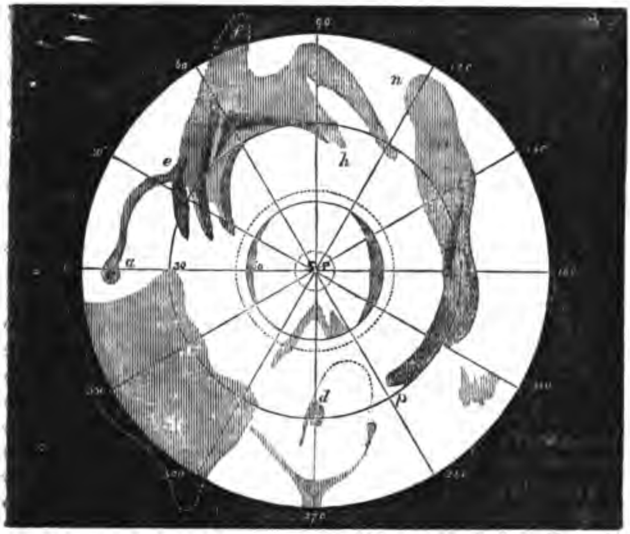
Thus we see that not only the same alternations of light and darkness but the same succession of seasons, regulated by nearly the same limits of temperature, the same diversity of climates, separated by nearly the same limits of latitude which prevail on Earth, have also been ordained for those three planets.

26. The atmosphere which surrounds the earth is an appendage which has an obvious and important relation to the animal and vegetable kingdoms. That respiratory beings depend on it for the maintenance of their vitality is obvious. The mechanical and chemical apparatus of the breathing organs is expressly adapted to it. Its relation to vegetable life is not less important.

But besides these qualities, without which life would become extinct on the surface of the globe, the atmosphere administers to our convenience and pleasures in other ways. It is the medium by which sound is transmitted; and as the apparatus of the lungs is adapted to operate chemically upon it, so as to impart to the blood the principle by which that fluid sustains life, so the exquisite mechanism of the ear is constituted to receive the effects of its pulsations and convey them to the *sensorium* to produce the perception of sound. Again, the mechanism of the organs of voice is adapted to impress on the atmosphere those pulsations, and thereby to convey its intonations to the correspondingly susceptible organisation of the ear. Without the atmosphere, therefore, even supposing we could live in its absence, however perfect might be our organs of speech and hearing, we should possess them in vain. Voice we might have, but no word could we utter; listeners we might be, but no sound could we hear; endowed with the full powers of hearing and speaking, we should nevertheless be deaf and dumb.

Another important manner in which the atmosphere administers to our convenience is, by diffusing in an agreeable manner the solar light, and mitigating its intensity. In this respect, the atmosphere may be considered as performing in regard to the sun what the imperfect transparency of a ground-glass shade performs for the glare of the lamp. In the absence of an atmosphere, the light of the sun would only illuminate objects on which its direct rays would fall; we should have no other degrees of light but the glare of intense sunshine, or the most impenetrable darkness. Shade, there would be none; the apartment whose casement did not face the sun, at the mid-day would be as at midnight. The presence of a mass of air extending from the surface of the earth upward to a height of more than forty miles, becomes strongly illuminated by the sun. This air reflects the solar light on every object exposed to it, and as it spreads over every part of the earth's surface, it conveys with it the reflected, but greatly mitigated light of the sun.

When the evening sun withdraws its light, the atmosphere continuing to be illuminated by its beams, supplies the gradual declining twilight which terminates in the shade of night. Before it rises, in like manner, the atmosphere is the herald of its coming, and prepares us for its splendour by the grey dawn and increasing intensity of morning twilight. In the absence of an atmosphere, the moment of sunset would be marked by an abrupt and instantaneous transition from the blaze of solar light to the most impenetrable darkness; and for the same reason, the morning would be characterised by an equally abrupt change from absolute darkness to broad, unmitigated sunshine.



MARS.

SKETCH OF THE OUTLINES OF CONTINENTS AND OCEANS, AND THE SNOW REGION OF THE POLAR CIRCLE ON THE SOUTHERN HEMISPHERE OF THE PLANET MARS, FROM THE OBSERVATIONS OF MÄDLER.

THE PLANETS:

ARE THEY INHABITED WORLDS?

CHAPTER II.

1.—Uses of an atmosphere—colour of sky.—2. Its effects on temperature.—3. Planetary atmospheres observable.—4. Clouds visible in them.—5. Hence rain, hail, and snow.—6. Winds manifested on the planets.—7. Clouds on Mercury, Venus, and Mars.—8. Continents and oceans.—9. Effect of gravity on planets.—10. Its relation to organised beings.—11. Adaptation of organised beings to the force of gravity—12. Gravity on Mercury, Venus, and Mars.—13. Solar system—Planets.—14. Number of planets—groups.—15. Inner group—the twenty-five grouped round the sun.—16. The outer group—Jupiter, Saturn, Uranus, and Neptune.—17. Their distances from the sun, from each other, and from the earth.—18. Apparent diameters of Sun's disk as seen from these planets—Sun's light and heat.—

19. Question of habitability of these planets considered in reference to sun's light and heat.—20. Great comparative magnitude of these planets—Their volumes—Question of habitability continued.—21. Proportionate population, if inhabited.—22. Investigation of physical causes incompatible with their being habitable globes.—23. Application of such causes to Jupiter, and reasoning thereon—Necessity of organised world being different from that on the earth.—24. Comparative volume and density of the Earth and Jupiter.—25. Comparison of relative quantities of gravitating matter in Saturn, Uranus, and Neptune, and in the Earth—and of density.—26. Comparative weights of bodies placed upon such planets and on the Earth.—27. General results of inquiry as to the habitability of these planets.—28. Atmosphere of these planets.—29. Their diurnal revolution—General observations on rotation and their results—Position of axis of rotation.

1. In the absence of an atmosphere we could have no clouds; day would be one unvaried wearisome glare of the sun. The bright azure sky, so grateful to the sight, is nothing more than the natural colour of the air reflected to the eye. The air which fills a room is not perceived to be blue only because it is not present in sufficient quantity to excite in the eye any perception of its colour; just as a glass of sea-water seems translucent and colourless, while the same water viewed through a considerable depth, appears with its proper hue of green.

When we look up, therefore, through forty miles of air, we behold that fluid of its proper tint of blue. In the absence of the atmosphere the great vault of the heavens would present one unvaried and eternal black, the stars dimly twinkling here and there, the whole forming a most funereal contrast with the bright orb which would be seen holding its solitary course through this eternal expanse of darkness.

2. The atmosphere produces effects on the temperature of our habitation which are not less important. It retains and diffuses warmth, whether proceeding from the sun above, or from sources of internal heat within the globe itself. What situation with respect to temperature we should be placed in by its absence, or even by a considerable diminution of its quantity or density, may be easily inferred by considering the state of those parts of the earth which are placed at such an altitude as to leave below them a large portion of the atmosphere. The summits of lofty ridges, such as those of the Alps, the Andes, and the Himalayah, are examples of this. No intensity of direct solar heat can compensate for the absence of a sufficiently dense atmosphere, and even within the tropics, water cannot exist in a liquid form at elevations above 14,000 feet. The summits of the Andes are clothed in everlasting snow.

Had we, therefore, been unprovided with an atmosphere, or even had our atmosphere been so rare and attenuated as it is at an elevation of three miles (scarcely one-tenth of its whole height), the waters of our oceans would have been solid. Vegetation could never have existed, and in spite of the light and genial warmth of the sun—in spite of the grateful changes of season—in spite of the beautiful and simple provision by which spring succeeds winter, and is followed by summer and autumn, the earth would have been a barren and arid waste, enveloped in a shell of eternal ice, devoid of life, motion, form, and beauty.

Seeing, then, how necessary to the existence of an animal and vegetable world an atmosphere is—how indispensable its presence is to a society of creatures whose means of intercommunication is sound—and yet bearing in mind at the same time that this atmosphere is not essential to any of the great mechanical functions of the earth in the economy of the solar system—considering also that without its presence the part which that earth, as a whole, performs in the society of the planets, would be the same as it now is—can we come to any other conclusion than that this atmosphere was cast around the earth expressly with a view to the well-being of its occupants—to afford them a genial warmth—to give them diffused and gentle light—to convey the varieties of sound—to promote and facilitate social felicity, by supplying the means of intercommunication by language—to preserve the seas liquid—and supplying propitious winds to stimulate the intercourse of nations and knit together the races of beings who occupy its most distant points by the kindly bonds of reciprocal beneficence? If then such be admitted to be some among the many of the purposes and uses of our atmosphere, the question whether other planets, in situations resembling ours, are occupied by similar beings, must be materially influenced by the result of an investigation as to whether or not these planets are supplied with like atmospheres.

3. Telescopic observations have most clearly and satisfactorily answered this question. The atmospheres around the planets are as palpable to sight as the clouds which float on our own. Venus and Mercury are enveloped in thick atmospheres: in the former the air is especially conspicuous, nay, we can even see the morning and evening twilight in that distant world. The atmosphere of Mars is likewise apparent. We see the clouds floating on it.

4. The ascertained existence of clouds in the planets proves more than the mere presence of atmospheres upon them. An atmosphere is necessary to support clouds, but must not be

identified with them. Clouds are no more parts of the atmosphere than the mud and sand which float in a turbid river are parts of its waters. Water is converted into vapour by the agency of the sun and wind. This vapour, when it escapes from the surface of the liquid, is generally lighter, bulk for bulk, than that part of the atmosphere contiguous to it. It rises into more exalted regions, where, by the agency of cold, and by electricity, it is made to resume its liquid state, but in such minute particles that it floats and forms those semi-opaque masses called clouds. Clouds are, then, in fact, water existing in a very minute state of mechanical division, and affected in peculiar ways by electricity.

5. When these particles are caused to coalesce into drops or spherules of water—an effect which may arise from temperature or electricity, or both combined—their weight renders their further suspension impossible, and they descend to the surface in the form of rain: or if the cold be so great as to congeal the particles before they coalesce into globules, they descend in the form of snow; or, finally, if by the sudden evolution of heat caused by electrical influences their solidification is effected in drops, they come down in the form of hail.

Thus wherever the existence of clouds is made manifest, *there* WATER must exist; *there* EVAPORATION must go on; *there* ELECTRICITY, with its train of kindred phenomena, must reign; *there* RAINS must fall; *there* HAIL and SNOW must descend.

6. That healthful and refreshing winds agitate the atmospheres of the group of worlds in the centre of which our sun presides, and of which it is the common bond—that showers refresh their surfaces—that their climates and seasons are modified by evaporation—that their continents are bounded by seas and oceans—that intercourse is facilitated by winds which convert the surfaces of their waters into highroads for nations—these and a thousand other consequences of what has been here explained, all tending to one conclusion—that these various globes are placed in the system for the same purpose as the earth—that they are in fact, the dwellings of beings in all respects, even from their lowest physical wants to their highest social advantages, like ourselves, crowd upon the mind so thickly that we can scarcely give them expression in a clear and intelligible order.

It may be asked whether by immediate observation we may not perceive the geographical surfaces of the planets, so as to declare by direct survey their divisions of land and water, mountain and valley, and other varieties of surface.

Even the most superficial view of the subject will render apparent some great difficulties which must obstruct such an inquiry with respect to most of the planets. The very presence of those atmospheres and the clouds with which they are loaded, offers a serious obstruction to any observations having for their object to ascertain the geographical character of their surfaces. The great distance of some of them is a formidable obstacle to such an inquiry; still, where some peculiar circumstances favour the observation, something has been done in this investigation.

7. Venus and Mars, the two planets in the system which come nearest to the path of the Earth, are evidently the most eligible objects for such an inquiry, and sufficient has been ascertained, especially with regard to the latter planet, to draw very closely indeed the ties of analogy by which the planets are associated with the earth.

8. The existence of continents and oceans, and even the configuration of their outlines has been clearly traced on Mars. The snow which covers his polar regions during the winter, has been distinctly seen, and has even been observed partially to dissolve and disappear under the influence of the summer heat. The clouds with which Venus and Mercury are so constantly enveloped, combined with other obstructions peculiar to the positions of these planets, have rendered like observations respecting them impracticable. It has, nevertheless, been ascertained that their surface, like that of the Earth, is marked by mountain-chains of great elevation.

9. In tracing the analogies which prove the suitableness of the planets for habitable globes, and which connect them by ties of kindred with the earth, one of the most important and interesting is dependent upon the quantity of matter composing these planets, compared with their volumes or bulks. Let us see how this affects the condition of the organised creatures that dwell upon them.

10. All organised beings, whether animal or vegetable, are endowed with a certain limited amount of bodily strength. In the case of animals, which have powers of locomotion, this strength is regulated with reference to their weight, and the extent and quantity of motion necessary for their well-being on the surface of the globe. The structure of every animal is such, in the first place, as to give it strength to support and move its own body; but this is not enough; it must have a further amount of disposable force to enable it to supply its own wants by the pursuit of its prey; by the collection of its food; by the erection of its dwelling; and, in general, by its labour in the supply of its physical wants. In the case of vegetables, the strength must be sufficient to support its weight, and resist those external

disturbances to which it is exposed—such as the action of winds and other natural effects. But what, let us ask, regulates this necessary quantity of strength? What is the chief resistance which it has to overcome? We answer, mainly the weight of the creature itself. But again; what is this weight? It is a force produced by what? By the combined attractions of the whole mass of matter composing the globe of the earth, exercised upon the matter composing the creature itself; thus the weight of a man is merely the amount of the attraction of the globe of the earth exercised upon the matter composing the body of the man. The amount of this attraction, therefore, depends upon the quantity of matter in the earth; but not on that alone; it is a universal law of nature, that the energy of the attraction exerted by matter, is increased with the proximity of the attracted body to the centre of the attracted mass. Now, if the matter composing the globe of the earth were condensed into half its present bulk, all bodies placed upon the surface, being proportionally nearer the centre, would be attracted with greater energy; and, on the other hand, if the matter of the earth were swelled into a larger bulk, the distance of objects on the surface from the centre being proportionally increased, the energy of the attraction would be diminished. In the one case the weights of all bodies would be augmented, and in the other they would be diminished. The weights, then, of bodies placed on the surface of the earth depend conjointly on the mass of matter composing the earth, and on its density.

11. It is evident then, that the adaptation which we see usually to prevail between the strength of animals and plants and their weights, is, in reality, an exquisite harmony which is maintained between the strength of these infinitely various tribes of organised creatures, and the mass and density of the globe upon which they are placed; the slightest disturbance or change in this relation would utterly derange the fitness of things, and would render the globe and its occupants, whether animal or vegetable, unsuited to each other. The amount of attraction, or, to use the more familiar term, the weight of the body on the surface of the globe is, then, an index, so to speak, to the organisation of the creatures placed upon the globe. If we would, then, inquire respecting the probable organisation of the dwellers upon the planets, one of the means of our inquiry would be to ascertain what would be the weights of bodies upon their surfaces. Physical science enables us perfectly to accomplish this The masses of matter composing all the planets have been discovered with a great degree of precision. Their magnitudes have also been measured. Now, to ascertain the weights of bodies placed upon

the surface of any of them, it is only necessary to consider their masses and their magnitudes. The weight of a body placed upon any planet is greater or less, *cæteris paribus*, than the weight of a body placed upon the earth, just in proportion as the mass of matter in the planet is greater or less than the mass of matter in the earth. If the distance from the surface to the centre of the planet be double the corresponding distance in the case of the earth, then the weight of bodies upon its surface would, on that account alone, be four times less than in the case of the earth. But if, at the same time, the mass of matter in the planet were sixteen times greater than the mass of matter in the earth, then the weight of bodies on the planet, on that account alone, would be sixteen times greater. The weight, then, on the one score, would be sixteen times greater, and on the other, four times less; the result being that the actual weight under such circumstances would be four times greater than upon the earth. Such are the principles by which may be calculated the weights of bodies upon the surfaces of the different planets.

12. It has been found that the weights of bodies on the surface of Venus are nearly the same as on the Earth, but that on Mercury and Mars the weights of bodies are only half of those which they would have if placed on the Earth. The inference obviously is, that organised beings on Venus would require to be endowed with the same bodily strength exactly as upon the Earth, but that half the strength would suffice on Mars and Mercury. The numerous analogies which we have indicated give the highest degree of probability, not to say moral certainty, to the conclusion that the three planets, Mars, Venus, and Mercury, which, with the Earth, revolve nearest to the sun, are like the Earth appropriated by the Omnipotent Creator and Ruler of the Universe to races very closely resembling, if not absolutely identical with, those by which the Earth is peopled.

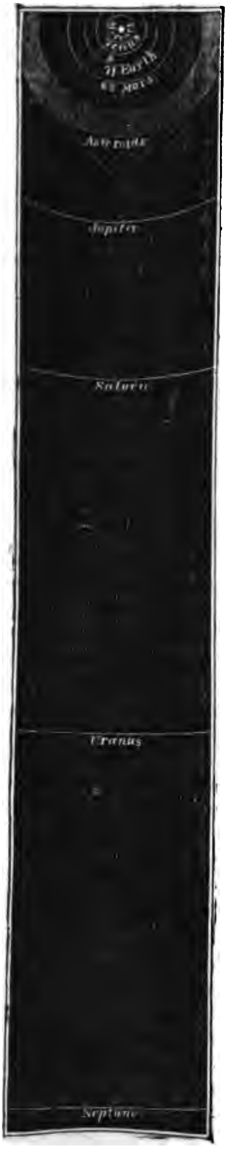
13. The solar system consists of the sun, a globe of stupendous magnitude, maintaining a position, relatively fixed in the centre, and thirty-three planets revolving round it in paths which do not differ sensibly from concentric circles.

14. These thirty-three planets are characterised by very striking differences in relative position and in magnitude, and have in relation to these differences been classed in three groups.

15. The inner group consists of four: Mercury, Venus, the Earth, and Mars. They are all included within a circle of 150,000000 of miles radius described round the sun as a centre, the distance of the earth being nearly 100,000000 of miles.

The circumstances attending these globes, their mutual analogies, and the probability, if not the moral certainty, that

Fig. 1.



they are the habitations of organised tribes similar to those which inhabit the earth having been very fully explained, we propose now to explain the circumstances which attend another of these groups.

The manner in which the thirty-three planets are distributed around the sun is represented in fig. 1. The relative distances are there represented as nearly as is practicable on their real scale. Twenty-five of the entire number of planets are crowded together at a distance from the sun about two-and-a-half times greater than that of the earth. These constitute a group apart, characterised by some very curious circumstances, which we shall explain hereafter.

16. The four outer planets, Jupiter, Saturn, Uranus, and Neptune, form the other group which we now propose to examine.

17. The relative distances of these bodies from the sun, from each other, and from the earth, are exhibited in the diagram (fig. 1), where the fifth part of an inch represents one hundred millions of miles. The distance of Jupiter from the sun on the plan being an inch, its real distance is, in round numbers, five hundred millions of miles. That of Saturn being $1\frac{8}{10}$ inch, that of Uranus $3\frac{6}{10}$ inches, and that of Neptune $5\frac{6}{10}$ inches; the actual distances of these three planets are 900, 1,800, and 2,800 millions of miles respectively, all the distances being, as before expressed, in round numbers.

18. When it is considered that the apparent magnitude of the sun and the intensity of its light and heat decrease in a very high proportion as its distance is augmented, it will be evident that that body, considered as the means of illumination and warmth, must minister to these several globes extremely different quantities of those necessary physical

principles. It has been already stated that the apparent diameter of the sun's disk is less in exactly the same proportion as the distance of the observer from that luminary is greater. Since, therefore, the distances of Jupiter, Saturn, Uranus, and Neptune are severally five, nine, eighteen, and twenty-eight times the earth's distance, the apparent diameters of the sun's disk, as seen from them, will be $\frac{1}{5}$, $\frac{1}{9}$, $\frac{1}{18}$, and $\frac{1}{28}$ of its diameter, as seen from the earth.

Fig. 2.

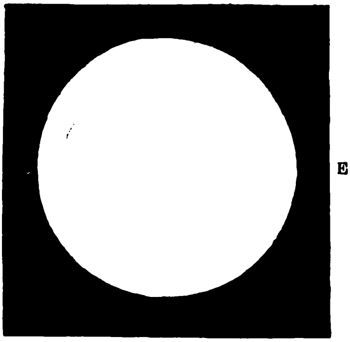
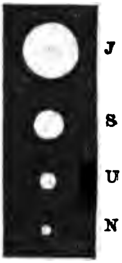


Fig. 3.



If the white circle E (fig. 2) be imagined to represent the apparent disk of the sun, as it is seen by an inhabitant of the earth, then J (fig. 3) will represent its appearance to an inhabitant of Jupiter, S its appearance to an inhabitant of Saturn, U to an inhabitant of Uranus, and N to an inhabitant of Neptune.

The light and heat which it would supply to each of these planets would be in the exact proportion of the apparent surface of the solar disk, and since the areas of circles are as the squares of their diameters, it would follow that the solar light and heat at Jupiter is 25 times, at Saturn 81 times, at Uranus 324 times, and at Neptune 784 times less than at the earth.*

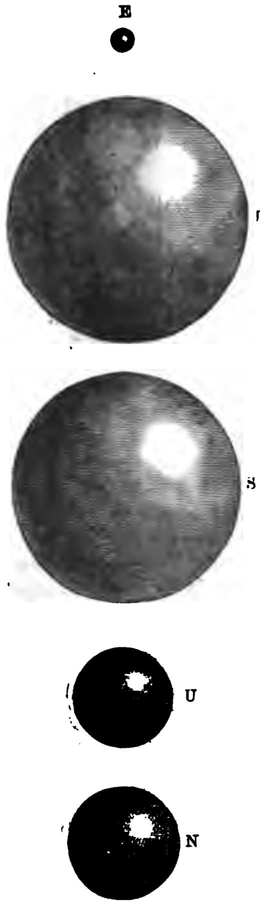
19. In considering the question of the habitability of these globes, it might appear from these numbers that the illuminating and heating power of the sun would be so diminished by distance as to be incompatible with the existence of organised races, at least on the more distant of those planets. It must, however, be considered that the illuminating power of the sun would be the same as at the earth, if only the pupils of the eyes were enlarged in the same ratio as the apparent superficial magnitude of the

---

* These numbers are not the exact ratios, but are near enough for the present illustration. For more precise results see "Handbook of Natural Philosophy and Astronomy" (2,994).

sun's disk is diminished, or that the same effect would be produced by a proportionally increased sensibility of the retina.

Fig. 4.



In like manner the diminished calorific power of the sun's rays proceeding from their diminished density, might be compensated by modified atmospheric conditions, just as we find with the same density of the solar rays all climates in ascending on tropical mountains to various altitudes from the level of the sea to the line of perpetual snow.

These points have been already so fully developed and explained, that we need not here further insist upon them.

It is apparent, therefore, that so far as the vastness of their distances from the sun compared with that of the earth affects the illumination and warmth supplied to them, there are no grounds for concluding that they may not be the habitations of races organised in a manner not differing in any important respect from those which inhabit the earth.

20. One of the most striking circumstances in which the group of planets now under consideration differ from the earth and the other three which form the terrestrial or inner group is their great comparative magnitude. The actual diameter of the earth is, in round numbers, 8000 miles. That of Jupiter is 88,000, that of Saturn 75,000, that of Uranus 35,000, and that of Neptune 37,500 miles. The diameter of Jupiter is therefore 11, that of Saturn 9½, that of Uranus 4⅓, and that of Neptune 4¾ times the diameter of the earth.

But the volumes or bulks of globes being in the proportion of the cubes of their diameters, it follows that the bulk of Jupiter is 1,330 times that of the earth ; and that those of Saturn, Uranus, and Neptune are respectively 857, 88, and 107 times that of the earth.

To render these vast proportions more clearly perceptible, we have represented them in the annexed figures. If E (fig. 4) be imagined to represent the globe of the earth, the globe of Jupiter will be represented on the same scale by J, that of Saturn by S, that of Uranus by U, and that of Neptune by N.

21. If they be inhabited globes analogous to the earth, they will accommodate a population as many times greater than that to which the earth is adapted, as their surfaces are greater than the surface of the earth ; and since the surfaces of globes are in the proportion of the squares of the diameters, Jupiter would afford space for habitation 121 times greater than the earth, and Saturn 90 times, Uranus 18 times, and Neptune 23 times greater.

22. It may, however, be asked whether this vast difference in the magnitude of these globes compared with that of the earth may not involve some physical consequences incompatible with the supposition of their being habitable globes at all analogous to the earth.

There is but one such consequence at all conceivable. It is that the effects of gravity upon them might be such as to be altogether unfitted for species organised like those of the earth. Thus, upon the earth the average strength of a man is adapted to support and give freedom of motion and action to a body whose average weight is an hundred and a half; that of a horse to one whose average weight is half a ton, and the like of other animals. The strength of the stalks and trunks of vegetables is in like manner adapted to their weights. In the same manner the materials of artificial structures have a strength which has like relation to their weights.

If these species, animal and vegetable, and these artificial structures were suddenly transferred to the surface of a planet, on which they would have several hundred times their present weight, the animals would not only be totally incapable of locomotion, but they, as well as the vegetables and artificial structures, would be crushed and crumbled to pieces under the enormous pressure of their own weights.

In discussing this question, it is therefore of the greatest importance to inquire whether the vast dimensions of this group of planets may not cause an increase of weight of bodies placed upon their surfaces so immense as to destroy all analogy to the earth considered as an inhabited globe.

In answer to this question, it may be replied that the weight of bodies placed upon the surface of a globe will depend conjointly on the quantity of matter in the globe, and on the distance of the body from its centre, which distance will be the radius or semi-diameter of the globe. The greater the quantity of matter composing the globe, the greater will be the attraction which it will exert upon a body at a given distance from its centre. But this attraction will be less as that distance is increased, in the proportion of the square of the distance.

23. Now let us apply these principles to the major planets;—to Jupiter for example.

The volume of Jupiter, as we have stated, is 1,330 times that of the earth. If it be composed of materials similar to those which compose the earth, its mass or quantity of matter will be 1,330 times greater than that of the earth, and it would consequently exert an attraction 1,330 times greater than terrestrial gravity upon a body *at the same distance from its centre.*

Now, the body of an average man placed on the surface of the earth, and therefore at a distance from its centre equal to half its diameter, is attracted towards that centre with a force of 150 lbs. The same body placed *at the same distance* from the centre of Jupiter would, on the above supposition, be attracted with a force of 1,330 times 150 lbs. But bodies placed on the surface of Jupiter are at a distance from its centre eleven times greater than the semi-diameter of the earth, because the semi-diameter of Jupiter is greater than that of the earth in the proportion of 11 to 1; and, consequently, if the body of the man were placed on the surface of Jupiter, it would be attracted with a less force in the ratio of the square of 11, that is of 121 to 1. The account would therefore stand thus:—

	lbs.
Weight of a man on the surface of the earth . .	150
Weight of do. placed at a distance from Jupiter's centre equal to the semi-diameter of the earth .	150×1330
Weight of do. removed to Jupiter's surface, the distance being thus increased 11 times . .	$\frac{150 \times 1330}{121}$

If we perform these arithmetical operations, multiplying 150 lbs. by 1,330, and dividing the product by 121 we shall obtain 1,648 lbs.

Thus it appears that if the materials of which the planet Jupiter is composed be similar to those of the earth, the weight of a man placed upon its surface would be greater than his weight upon the earth, in the ratio of 1,648 to 150, or about 11 to 1, and of course the weights of all bodies would be greater in the same proportion.

It is evident, that although such a physical condition would not at all exclude the possibility of Jupiter being an inhabited globe, it would require the admission, that the organised world upon it must be totally different from that which exists upon the earth.

But are the materials of which Jupiter is composed similar to those of the earth? If not, the conclusion at which we have arrived must be modified. The whole question resolves itself into the determination of the actual quantity of gravitating matter composing this stupendous planet compared with the quantity composing the earth. Now it will be apparent, that if we could ascertain the attractions which Jupiter and the earth would exert upon bodies placed at equal distances from them, these attractions would be the exact exponents of the quantities of gravitating matter composing these two globes.

This we are happily enabled to accomplish by a very simple and obvious arithmetical operation. The moon, as is well known, revolves in its monthly orbit round the earth, and is retained in that orbit by the attraction of the mass of gravitating matter composing the earth. If that mass were greater the moon would revolve faster, if less, slower. Its rate of motion is therefore an index to the quantity of gravitating matter composing the earth.

Jupiter like the earth is also attended, but by four and not by one moon. Each of these four moons is retained in its orbit round Jupiter by the attraction of the gravitating mass composing that planet. If it had happened that one of these four moons were at exactly the same distance from Jupiter's centre as the earth's moon is from its centre, then the motion of that moon would at once prove whether the quantity of matter composing Jupiter is greater or less than the quantity of matter composing the earth. If the moon of Jupiter being thus at the same distance moved faster than the earth's moon, the mass of Jupiter would be greater, and if it moved slower it would be less than the mass of the earth.

Although all the moons of Jupiter are more distant from its centre than the moon is from the earth's centre, the nearest of these moons to Jupiter is *not much* more distant. Yet this moon makes a complete revolution round Jupiter in forty-two hours, while the earth's moon, though *a little nearer* to the attracting mass, takes nearly 656 hours to make a revolution.

It is obvious, therefore, that the gravitating mass composing Jupiter must be vastly greater than that which composes the earth.

By allowing for the difference of distance of the two moons from the centres of the two planets, and by taking into account the exact proportion of their velocities, it has been found that the mass of gravitating matter composing Jupiter is 338½ times the mass of the earth.

The meaning of this is, that if 338½ masses of matter like the earth were placed in one scale of a colossal balance, and the single globe of Jupiter in the other, the beam would be exactly equipoised.

24. A very curious inference follows from this. It appears from what has been shown, that the volume or bulk of Jupiter is 1,330 times greater than that of the earth, so that it would require 1,330 globes like the earth to be moulded into a single globe to make such a globe as Jupiter, while 338½ such globes would be sufficient to make a globe as heavy as Jupiter. It is evident, therefore, that bulk for bulk, the matter composing Jupiter, is lighter than the matter composing the earth, in the ratio of 338½ to 1,330, or what is the same, of 4 to 1.

It has been proved that the earth is 5½ times the weight of an equal globe composed of water. It follows therefore that Jupiter is heavier than an equal globe of water in the far less proportion of 5½ to 4, or 1⅜ to 1.

It was shown that if Jupiter were composed of matter like the earth, the weight of bodies upon his surface would be 11 times greater than upon the earth. But since it appears that it is composed of matter 4 times lighter than that of the earth, it will follow that the weight of bodies upon its surface will be 4 times less than the weight previously computed, and that it will therefore be only 2¾ greater than upon the earth.

Thus it seems that owing to the comparative lightness of the matter composing this great globe, the attraction which it exerts upon bodies placed upon its surface, though greater than upon the earth, does not exceed terrestrial gravity in a proportion which requires the admission of any difference of organisation of the inhabitants, exceeding what may be imagined without removing Jupiter from the general analogy of the earth.

25. The other three planets of the exterior group, being attended by satellites, can be weighed against the earth by comparing, as in the case of Jupiter, the motions of their moons with that of the earth's moon, and after making due allowance for the difference of distance, the attractions which they would severally exert, compared with that exerted by the earth, becomes the expression of the relative quantities of gravitating matter compared with that of the earth.

It is thus found that the weight of Saturn is 101 times, that of Uranus 14¼, and that of Neptune 19 times the weight of the earth.

It appears, therefore, that while the bulk of Saturn is 857 times greater than that of the earth, its weight is only 101 times greater. It is therefore lighter, bulk for bulk, than the earth, in the proportion of 101 to 857, or 1 to 8½.

In like manner, while the bulk of Uranus is 82 times greater, its weight is only 14¼ times greater than that of the earth. It is therefore lighter, bulk for bulk, than the earth, in the proportion of 14¼ to 82, or 1 to 6 very nearly.

In fine, while the bulk of Neptune is 107 times greater, its weight is only 19 times greater than the earth, and it is therefore lighter, bulk for bulk, than the earth, in the proportion of 19 to 107, or nearly 1 to 6, the same as Uranus.

It has been proved that the earth is, bulk for bulk, 5½ times heavier than water. It follows therefore that Saturn being 8½ times lighter, bulk for bulk, than the earth, is lighter, bulk for bulk, than water in the proportion of 5½ to 8½, or 1 to 1½.

In like manner it appears that Uranus and Neptune, being nearly six times lighter, bulk for bulk, than the earth, must be composed of materials equal in weight, bulk for bulk, with water.

The weight of Jupiter is equal to that of some of the denser sorts of wood, such as lignum vitæ or ebony, and that of Saturn is equal to the weight of the lighter sorts, such as deal.

26. The weight of bodies placed upon the surfaces of Saturn, Uranus, and Neptune, are ascertained by comparing their masses with their magnitude, as in the case of Jupiter, and it is thus found that it does not differ much from their weights on the earth. On Saturn it is a very little more, and on Uranus and Neptune a little less.

27. It appears, therefore, that if these planets be inhabited, the same organisation which prevails on the earth would be sufficient to impart the same, or nearly the same, degree of stability and freedom of locomotion. A man, in fine, transferred from the earth to Saturn, Uranus, or Neptune, would not be sensible of much difference in his power of action and motion. Trees and other vegetables, with their present strength, would be equally stable, and artificial structures equally solid and durable.

28. The importance of the atmosphere to all the functions of animal and vegetable life, and its uses in the diffusion of light and the retention and diffusion of heat, have been fully explained. The existence of any atmosphere on a planet is, therefore, an essential condition necessary to bring it into analogy with the earth as an inhabited globe.

The atmospheres of Jupiter and Saturn are rendered conspicuously apparent by the telescope. We see the clouds floating in dense masses upon them; so dense indeed and so unbroken as to conceal from our view the characters of the surfaces of the planets themselves.

Uranus and Neptune are too remote for like observations in the present state of the telescope, but it is in the highest degree probable that with improved powers of that instrument, like appearances will be observed upon them.

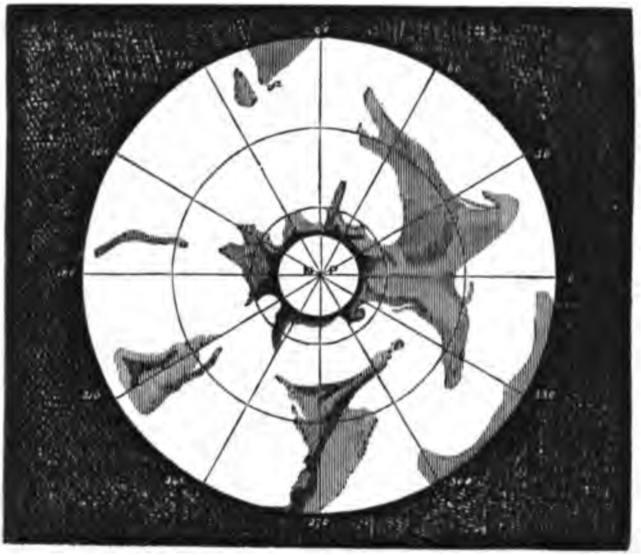
29. It might be imagined that the circumstance of being thus constantly enveloped in clouds would render it impossible to ascertain whether these planets, like the earth, turn upon an axis, and consequently have days and nights analogous to those of the earth.

It must be remembered, however, that the earth's atmosphere, and the clouds which float upon it, partake of the motion of diurnal rotation. and that if the atmosphere were perfectly calm for twenty-four hours, the various masses of clouds resting upon it being always suspended over the same parts of its surface, would be carried round with it, and would consequently make a complete rotation round the common axis in the same time exactly as the solid globe of the earth.

Now, if an observer placed upon any of the planets, not too remote, were in this case to direct a sufficiently powerful telescope to the earth, although he might not see the outlines of land and water, being enveloped by clouds, he would distinguish the masses of clouds themselves by their varieties of light and shade, and would see them carried round by the diurnal rotation—disappearing at one side and reappearing at the other; and he would thus not only ascertain the fact of the diurnal rotation of the earth, but also the time of rotation, that being the interval between two successive disappearances or reappearances of the same lineaments of light and shade, and the direction of the axis of rotation—that direction being at right angles to the apparent motion of rotation.

Circumstances, just such as these, have been observed to take place on Jupiter and Saturn. The masses of cloud, whose lights and shadows diversify their surfaces, though more or less shifting and variable, are at times found to remain fixed, as if the atmosphere were absolutely calm and quiescent for intervals sufficiently protracted to enable the telescopic observer to see the same lineaments disappear at one side of the disk, reappear at the other, and passing across the disk, again disappear. These are the obvious effects of the rotation of these planets upon an axis at right angles to the direction of this apparent motion.

Observations such as these, repeated and continued for long periods of time, have led to the discovery that Jupiter turns upon a certain diameter with a diurnal motion, making a complete revolution in 9^h 55^m 26^s terrestrial time, and that Saturn revolves in like manner, and what is more remarkable in a time not very different from that of the rotation of Jupiter. Saturn's rotation is completed in 10^h 29^m 17^s.



MARS.

SKETCH OF THE OUTLINES OF CONTINENTS AND OCEANS, AND THE SNOW REGION OF THE POLAR CIRCLE OF THE NORTHERN HEMISPHERE OF THE PLANET MARS, FROM THE OBSERVATIONS OF MÄDLER.

THE PLANETS:

ARE THEY INHABITED WORLDS?

CHAPTER III.

1. Diurnal rotation of Uranus.—2. Inclination of the axes and limitation of the seasons on the Major planets.—3. Jovian zones and climates.—4. Saturnian.—5. Short days and nights of Major planets.—6. Lightness of their materials.—7. Oceans and seas must consist of a liquid lighter than water.—8. Jovian, Saturnian, and Uranian years.—9. Effects of diurnal rotation on the distribution of clouds.—10. These effects more conspicuous in the Major planets.—11. Manifested by the belts.—12. Telescopic appearance of Jupiter.—13. Herschel and Mädler's telescopic views of Jupiter.—14. Jupiter elliptical in form.—15. Discovery of Jupiter's moons. —16. Short months.—17. Lunar eclipses.—18. Telescopic appearance of Jupiter's satellites.—19. As seen from Jupiter.—20. The Saturnian system.—21. Atmosphere and moons.

1. Conclusive and satisfactory observations of this kind have not yet been made on Uranus, but from the observations, imperfect as they are which have been made, there are probable grounds for the inference that this planet also revolves on an axis in nine hours and a half.

Thus it appears that these vast globes, revolving at distances from the sun from five to thirty times that of the earth, have like the earth alternations of light and darkness; that they have days and nights; that all parts of their surfaces are in turn, like those of the earth, presented to the common centre of light and warmth, but that the intervals which regulate these alternations, "the division of the light from the darkness," which has been found good by Divine beneficence for the races which inhabit the earth, has not been found "good" for those which inhabit those more remote worlds. The average length of the day on them is about five hours, while it is twelve upon the earth.

The creatures placed upon these planets must, therefore, be so constituted as to require more frequent intervals for rest and sleep, and shorter periods of wakefulness, activity, and labour, than those which inhabit the earth.

2. The position of the axis of rotation has been ascertained in the cases of Jupiter and Saturn, but not as yet of the other two planets of this group.

The axis of Jupiter is inclined to the plane of its orbit at the very small angle of 3° 5′ 30″, while that of the earth, as is well known, has an inclination of 23° 28′ 30″.

As this inclination limits the temperature of the seasons, the extent of the zones and the varieties of the climates, it follows, that on Jupiter these phenomena must be very different from those of the earth. The extreme variation of the altitude of the sun at noon does not much exceed six degrees in any latitude, a change which cannot produce any very sensible variation in the temperature of the seasons. On this planet there is, therefore perpetual spring.

3. The tropics of Jupiter are only three degrees north and south of his equator, and the polar circles, which include the only parts of the planet at which the sun remains at any time below or above the horizon during a complete revolution, are limited to three degrees around the poles.

In fine, the diurnal phenomena on Jupiter are, at all times, nearly the same as they are upon the earth at the Equinoxes.

4. The case is very different with Saturn, which presents a closer analogy to the earth. The direction of the diurnal motion, in the case of that planet, makes an angle of 26° 48′ 40″, with the plane of the orbit differing little from the angle which the ecliptic

makes with the terrestrial equator. The Saturnian seasons, zones, and climates are, therefore, absolutely similar to those of the earth. The tropical and polar phenomena are the same.

It is to be hoped that the recent improvements effected by Lord Rosse, in the construction of reflecting telescopes, may place it within the power of observers to determine the position of the axes of Uranus and Neptune, and the line of rotation of the latter.

5. So far as discovery has hitherto proceeded, it would appear that a comparatively greater rapidity of rotation, and shorter intervals of light and darkness, is a characteristic by which the group of major planets are distinguished from the terrestrial group.

6. A second striking distinction between these two groups is the comparative lightness of the matter composing the former. It will be remembered that, in our notice of the terrestrial group, we showed that the density of the matter composing the earth, Venus, and Mars is nearly equal, and is five-and-a-half times that of water, and about the same as that of iron-stone, while the density of the planet Mercury is equal to that of gold. Now, it appears that, on the contrary, the density of Jupiter very little exceeds that of water, that of Uranus and Neptune is exactly that of water, while Saturn is so light that it would float in water like a globe of pine-wood.

It must be admitted to be not the least striking among the wondrous results of human sagacity, that these remote globes have been submitted to such an analysis as enables us thus to pronounce with certainty upon one, at least, of the physical characters of their constituent parts. In some instances science has even gone further, and has shown that the densities of Jupiter and Saturn cannot be uniform, but must increase gradually as that of the earth is known to do, from the surface to the centre, and from this it follows that the mean density of the matter of their surface must be much less than that of water.

7. It follows, therefore, that the seas and oceans of these planets must consist of a liquid far lighter than water. It is computed that a liquid on Jupiter, which would be analogous to the terrestrial oceans, would be three times lighter than sulphuric ether, the lightest known liquid, and would be such that cork would scarcely float in it.

8. The rapid rotation of these planets, combined with the great length of their revolution round the sun, gives them years consisting of a vast number of days. The year of Jupiter is nearly twelve terrestrial years, or, more exactly, $4332\frac{6}{10}$ terrestrial days. But as the Jovian days are shorter than the

terrestrial in the ratio of 1 to 2·42, it follows that in a Jovian year there are 10485 Jovian days.

The Saturnian year is equal to 29½ terrestrial years, or more exactly to 10,759 terrestrial days, and since the Saturnian day is shorter than the terrestrial in the ratio of 1 to 2·3, it will follow that the Saturnian year consists of 24746 Saturnian days.

Thus each of the Saturnian seasons, spring, summer, autumn, and winter is equal to seven-and-a-half terrestrial years.

The Uranian year is equal to 84 terrestrial years, or 30687 terrestrial days; and the Uranian day, according to the probable estimate, being shorter than the terrestrial day in the ratio of 1 to $2\frac{520}{1000}$, it follows that the Uranian year consists of 77336 Uranian days.

If the axis of Uranus be inclined to the plane of its orbit like that of Saturn, its seasons will be similar to those of the earth, but of very different duration, their length being 21 terrestrial years, or 19334 Uranian days.

9. One of the most remarkable meteorological consequences of the diurnal rotation of the earth is the system of atmospheric currents, which, in both hemispheres, are directed generally parallel to the equator, and which, from their great permanence and regularity in the lower latitudes, have, in all ages since the invention of ocean navigation, subserved the purposes of commerce so extensively as to have acquired the name of the trade-winds. These phenomena will be explained more fully, so far as relates to their physical causes, in another part of this series. What we now desire to direct attention to is their effects in the upper strata of the atmosphere.

It is evident that such currents must have a general tendency to distribute the strata of clouds in lines or streaks, more or less pronounced, according to their intensity and regularity, parallel to the equator. If these aërial currents were much more intense and much more permanent and regular, and if the clouds themselves were more voluminous and permanent than they are, this distribution of them in streaks or layers at right angles to the earth's axis would be in proportion more pronounced, more regular, and more permanent.

The causes of these atmospheric currents are traced to the combined effects of the velocity with which the atmosphere is carried round with the earth on its axis, and the influence of the solar heat produced upon the zone of atmosphere over those regions of the globe which extend to a certain distance north and south of the equator.

If the velocity with which the atmosphere is carried round were much greater than it is, and if the atmosphere were more constantly and heavily loaded with clouds, these effects would be much more striking.

The velocity with which the atmosphere is carried round would be greater if the earth's rotation were more rapid. It would also be greater, even with the present rate of rotation, if the earth were a larger globe, because then the atmosphere would be carried in the same time round a proportionately greater circumference. But if both these conditions were at the same time fulfilled—if the earth revolved more rapidly on its axis, and were at the same time a larger globe, the atmosphere would be not only carried round in a less time, but would revolve through a larger circumference.

10. Now this is exactly the case with the major planets. Jupiter, Saturn, and Uranus make each about five revolutions on their axes while the earth makes two, and the equatorial circumference of Jupiter is eleven times, that of Saturn above nine times, and that of Uranus more than four times greater than the equatorial circumference of the earth.

The speed with which the equatorial zone of air is whirled round on Jupiter is therefore about 27 times, on Saturn 23 times, and on Uranus about 7 times greater than on the earth.

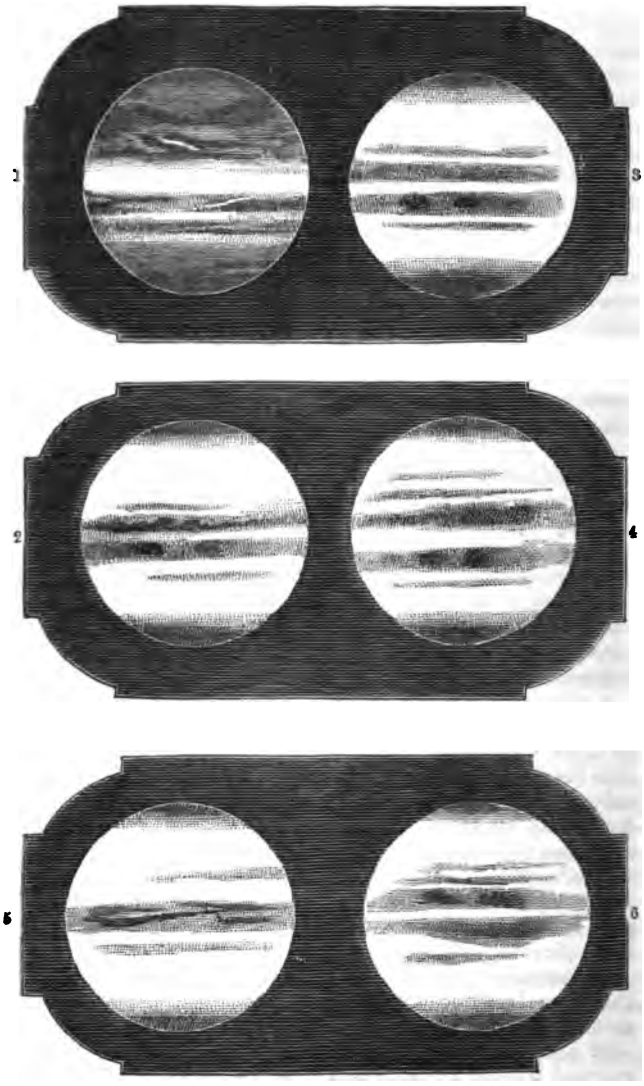
We find by telescopic observation also, as has been already stated, that the atmospheres of these planets are so thickly and constantly loaded with clouds that the surfaces of the solid globes are permanently concealed from us.

It may, therefore, be inferred that the prevalence of atmospheric currents on these planets parallel to their equators are far more constant and more strong than upon the earth; and since the masses of cloud with which they are loaded are greater and more permanent, the effects of such currents upon their distribution in equatorial strata or bands must be supposed to be far more conspicuous.

11. Observation has confirmed this in a most remarkable and interesting manner. Look at the six telescopic views of Jupiter, given in figures 1 to 6 (page 38), which are engraved after the telescopic drawings of Herschel and Mädler.

The streaks parallel to the Jovian equator are conspicuous. These streaks, which were seen not long after the invention of the telescope, are called "Jupiter's Belts."

Of all the bodies of the system, the moon perhaps alone excepted, Jupiter presents to the telescopic observer the most magnificent spectacle. Notwithstanding its vast distance, such is its stupendous magnitude that it is seen under a visual angle nearly twice that of Mars. A telescope of a given power, therefore, shows it with an apparent disc four times greater. It has



SIX TELESCOPIC VIEWS OF JUPITER.

1. Sept. 23, 1832. 2. Dec. 23, 1834. 3. Dec. 23, 1834.
4. Jan. 2, 1836. 5. Jan. 16, 1836. 6. Jan. 17, 1836.

consequently, been submitted to examination by the most eminent observers, and its appearances described with great minuteness of detail. The apparent diameter in opposition (when it is on the meridian at midnight) is about the fortieth part of that of the moon, and therefore a telescope with the very moderate magnifying power of forty, presents it to the observer with a disc equal to that with which the full moon is seen with the naked eye.

A power of four or five is sufficient to enable the observer to see the planet with a sensible disc; a power ot thirty shows the more prominent belts; a power of forty shows it with a disc as large as that which the full moon presents to the naked eye; but to be enabled to observe the finer streaks which prevail at greater distances from the planet's equator, it is not only necessary to see the planet under favourable circumstances of position and atmosphere, but to be aided by a well-defining telescope with magnifying powers varying from 200 to 300.

The planet, when thus viewed, appears to exhibit a disc, the ground of which is a light yellowish còlour, brightest near its equator, and melting gradually into a leaden-coloured gray towards the poles, still retaining, nevertheless, somewhat of its yellowish hue. Upou this ground are seen a series of brownish-gray streaks, resembling in their form and arrangement the streaks of clouds which are often observed in the sky on a fine calm evening after sunset. The general direction of these streaks is parallel to the equator of the planet, though sometimes a departure from strict parallelism is observable. They are not all equally conspicuous or distinctly defined. Two are generally strikingly observable, north and south of the equator, separated by a bright yellow zone, a part of the general ground of the disc. These principal streaks commonly extend around the globe of the planet, being visible without much change of form during an entire revolution of Jupiter. This, however, is not always the case, for it has happened, though rarely, that one of these streaks, at a certain point, was broken sharply off, so as to present to the observer an extremity so well defined and unvarying for a considerable time as to supply the means of ascertaining, with a very close approximation, the time of the planet's rotation. The borders of these principal streaks are sometimes sharp and even, but, sometimes (those especially which are further from the equator), rugged and uneven, throwing out arms and offshoots.

On the parts of the disc more remote from the equator, the streaks are much more faint, narrower, and less regular in their parallelism, and can seldom be distinctly seen, except by practised observers, with good telescopes. With these, however, what appears near the poles, in instruments of inferior power, as a dim shading of a yellowish-gray hue, is resolved into a system of fine parallel streaks in close juxtaposition, which becoming closer in approaching the pole, finally coalesce.

In general, all the streaks become less and less distinct towards either the eastern or western limb, disappearing altogether at the limb itself.

Although these streaks have infinitely greater permanency than the arrangements of the clouds of our atmosphere, and are even more permanent than is necessary for the exact determination of the planet's rotation, they are nevertheless entirely destitute of that permanence which would characterise Zenographic features, such as are observed, for example, on Mars. The streaks, on the contrary, are subject to slow but evident variations, so that after the lapse of some months the appearance of the disc is totally changed.

12. These general observations on the appearance of Jupiter's disc will be rendered more clearly intelligible by reference to the telescopic drawings of the planet given in fig. 1 to 6. In fig. 1 is given a telescopic view of the disc by Sir John Herschel, as it appeared in the 20-feet reflector at Slough on the 23rd September, 1832. The other views were made by M. Mädler from observations taken in 1835 and 1836, at the dates indicated on the plate.

The two black spots represented in figs. 2, 3, and 4, were those by which the time of rotation was determined. They were first observed by Mädler, on the 3rd November, 1834. The effect of the rotation on these spots was so apparent that their change of position with relation to the centre of the disc, in the short interval of five minutes, was quite perceivable. A third spot, much more faint than these, was visible at the same time, the distances separating the spots being about 24° of the planet's surface. It was estimated that the diameter of each of the two spots represented in the diagrams was 3,680 miles, and the distance between them was sometimes observed to increase at the rate of half a degree, or 330 miles, in a month. The areas of these spots must therefore have been nearly equal to a fourth part of the entire surface of the earth. The two spots continued to be distinctly visible from the 3rd of November, 1834, when they were first observed, until the 18th of April, 1835; but during this interval the streak on which they were placed had entirely disappeared. It became gradually fainter in January (see fig. 4), and entirely vanished in February: the spots, however, retaining all their distinctness. The planet, after April, passing towards conjunction, was lost in the light of the sun;

and when it re-appeared in August, after conjunction, the spots had altogether vanished.

The observations being continued, the drawings (figs. 5 and 6), were made from observations on the 16th and 17th of January, 1836, when the entire aspect of the disc was changed. The two figures (5 and 6) represent opposite hemispheres of the planet.

It was remarked that the two spots, when carried round by the rotation, became invisible at 55° to 57° from the centre of the disc. This is an effect which would be produced if the spots were openings in the mass of clouds floating in the atmosphere of the planet. Their disappearance on moving from the centre of the disc would be caused by their deep sides intercepting the view of their bottom, just as we should lose sight of a railway in a deep cutting, if, being placed at the edge of the cutting, we were to withdraw to some distance from it.

A proper motion with a slow velocity, and in a direction contrary to the rotation of the planet, was observed to affect the spots, and this motion continued with greater uniformity in March and April, after the disappearance of the belt.

It was calculated that the velocity of their proper motion over the surface of the planet was at the rate of from three to four miles an hour.

Although the two black spots were not observed by Mädler until the first days of November, they had been previously seen and examined by Schwabe, who observed them to undergo several curious changes, in one of which one of them disappeared for a certain interval, its place being occupied by a mass of fine dots. It soon, however, re-appeared as before.

From all these circumstances, and many others developed in the course of his extensive and long-continued observations, Mädler considers it highly probable, if not absolutely certain, these vast masses of clouds have a permanence of form, position, and arrangement to which there is nothing analogous in the atmosphere of the earth, and that such permanence may in some degree be explained by the great length and very small variation of the seasons. He thinks it probable that the inhabitants of places in latitudes above 40° never behold the firmament at all, and those in lower latitudes only on rare occasions.

It is also probable that the bright yellowish general ground of Jupiter's disc consists of clouds, which reflect light much more strongly than the most dense masses which are seen illuminated by the sun in our atmosphere ; and that the darker streaks and spots observed upon the disc are portions of the atmosphere, either free from clouds and through which the surface of the planet is visible more or less distinctly, or clouds of less density and less reflecting power than those which float over the general atmosphere and form the ground on which the belts and spots are seen.

That the atmosphere has not any very extraordinary height above the surface of the planet is proved by the sharply defined edge of the disc. If its height bore any considerable proportion to the diameter of the planet, the light towards the edges of the disc would become gradually fainter, and the edges would be nebulous and ill-defined. The reverse is the case.

13. One of the most remarkable consequences of the rotatory motion, which has been the means of giving to the inhabitants of the earth the alternations of day and night, is that its figure has been changed from that of a perfect sphere to an oblate spheroid; that is, a globe flattened at the poles. This has been already explained.

If the diurnal rotation of the earth were more rapid than it is, this polar flattening would be more considerable. In short, the degree of oblateness, or the proportion in which the polar axis is shorter than the equatorial diameter, depends on the time of rotation in such a manner, that this time being known, that proportion can be computed, or *vice versâ.*

Now, the rotation of these major planets being ascertained, and being much more rapid than that of the earth, it would follow that they must be oblate spheroids, and that their degree of oblateness must be much greater than that of the earth. Observation fully confirms this.

The disc of Jupiter, seen with magnifying powers as low as 30, is evidently oval, the lesser axis of the ellipse coinciding with the axis of rotation, and being perpendicular to the general direction of the belts; as in the case of the earth, the degree of oblateness of Jupiter is found to be that which would be produced upon a globe of the same magnitude, having a rotation such as the planet is observed to have.

At the mean distance from the earth, the apparent diameters of the disc are ascertained by exact micrometric measures to be—

	Miles.
Equatorial Diameter	38·4″=92080
Polar Diameter	35·6″=85210
Mean Diameter	=88645

The polar diameter is therefore less than the equatorial, in the ratio of 356 to 384, or 100 to 108 nearly. Other estimates give the ratio as 100 to 106.

This is just the proportion which would be produced by a rotation like that which Jupiter is ascertained to have.

14. However agreeable may be the light of the moon in the absence of the sun, that attendant is not indispensable to the well-being of the inhabitants of the earth; and of the inner group of planets the earth alone has been supplied with such a supplement to the solar illumination.

The planets constituting the outer group are, however, much more munificently provided with this convenience, each being supplied with so many moons that their nights must be perpetually moonlit.

When Galileo directed the first telescope to the examination of Jupiter, he observed four minute stars, which appeared in the line of the equator of the planet. He took these at first to be fixed stars, but was soon undeceived. He saw them alternately approach to and recede from the planet, observed them pass behind it and before it, and oscillate, as it were, to the right and left of it, to certain limited and equal distances. He soon arrived at the obvious conclusion that these were bodies which revolved round Jupiter in orbits, at limited distances, and that each successive body included the orbit of the others within it; in short, that they formed a miniature of the solar system, in which, however, Jupiter himself played the part of the sun. As the telescope improved, it became apparent that these bodies were small globes, related to Jupiter in the same manner exactly as the moon is related to the earth; that, in fine, they were a system of four moons, accompanying Jupiter round the sun.

15. But connected with these appendages there is perhaps nothing more remarkable than the period of their revolutions. That moon which is nearest to Jupiter completes its revolution in forty-two hours. In that brief space of time it goes through all its various phases; it is a thin crescent, halved, gibbous, and full. It must be remembered, however, that the day of Jupiter, instead of being twenty-four hours, is less than ten hours. This moon, therefore, has a month equal to a little more than four Jovian days. In each day it passes through one complete quarter; thus, on the first day of the month it passes from the thinnest crescent to the half moon; on the second, from the half moon to the full moon; on the third, from the full moon to the last quarter; and on the fourth returns to conjunction with the sun. So rapid are these changes that they must be actually visible as they proceed.

The apparent motion of this satellite in the firmament of Jupiter is at the rate of more than 8° per hour, and is the same as if our moon were to move over a space equal to her own apparent diameter in rather less than four minutes. Such an object would serve the purpose of the hand of a stupendous celestial clock.

The second satellite completes its revolution in about eighty-five terrestrial hours, or about eight and a half Jovian days. It passes, therefore, from quarter to quarter in twenty-one hours, or about two Jovian days, its apparent motion in the firmament being at the rate of about 4·25° per hour, which is as if our moon were to move over a space equal to nine times its own diameter per hour, or over its own diameter in less than seven minutes.

The movements and changes of phase of the other two moons are not so rapid. The third passes through its phases in about 170 hours, or seventeen Jovian days, and its apparent motion is at the rate of about 1° per hour. The fourth and last completes its changes in 400 hours, or forty Jovian days, and its apparent motion is at the rate of little less than 1° per hour, being double the apparent motion of our moon.

Thus the inhabitants of Jupiter have four different months, of four, eight, seventeen, and forty Jovian days respectively.

16. Jupiter's moons differ from that of the earth, inasmuch as all of them move in the plane of the planet's equator, from which plane the sun can never depart further than about 3°. At and for a considerable time before and after the Jovian equinoxes, the sun is so very near the planet's equator that each of the moons, which never leave that equator, must necessarily pass between the sun and the planet every revolution. It follows, therefore, that for a long interval before and after each of the equinoxes, solar eclipses will be produced by each of the four moons every revolution. These eclipses, however, will be visible only at certain low latitudes. The inhabitants of the higher latitudes in either hemisphere will be so far removed from the common direction of the moons and sun, or what is the same, from the plane of the Jovian equator, that the visual line directed to the sun will be clear of the moons.

The shadow of this vast globe is so prodigious in its dimensions that the three inner moons never pass behind Jupiter without passing through it. They are therefore invariably eclipsed every revolution; and since at the time these moons would appear full they are in direct opposition to the sun, they are then plunged in the shadow, and therefore eclipsed. The Jovians consequently never see any of these three moons when they are full.

The fourth or most remote of the moons is, like the others, generally eclipsed every revolution; but at the Jovian seasons of midsummer and midwinter, for a certain interval, the sun, and consequently the shadow of the planet, are sufficiently removed from the plane of the planet's equator to enable this moon to clear the boundary of the shadow, and to pass through opposition without entering it. This is the only case in which any of the moons can ever pass through opposition without also passing through the shadow of the planet, and consequently the only times the Jovians ever enjoy the spectacle of a full moon.

When these circumstances are combined with the rapid revolution of the moons, it will be easily understood that the celestial phenomena of the Jovians must offer great variety, and that their chronology must be curiously complicated. A total lunar eclipse of the first or nearest moon must take place every forty-two terrestrial hours, that is, every fourth Jovian day; and for a long interval before and after the equinoxes a total or partial solar eclipse must take place at like intervals, being alternated with the lunar eclipses, and separated from them by intervals of only twenty-one terrestrial hours, or two Jovian days.

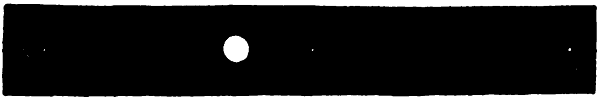
The same phenomena exactly take place with relation to the second satellite, at intervals of 3½ terrestrial, or about 8½ Jovian days; to the third at intervals of 7 terrestrial, or 17 Jovian days; and to the fourth at intervals of 16½ terrestrial, or 40 Jovian days, subject, nevertheless, with respect to the last, to an interruption at the Jovian summer and winter, from the cause already explained.

17. The appearance which the satellites of Jupiter present when viewed with a telescope of moderate power, is that of minute stars ranged in the direction of a line drawn through the centre of the planet's disc, nearly parallel to the direction of the belts, and therefore coinciding with that of the planet's equator.

The entire system is comprised within a visual area of about two-thirds of the apparent diameter of the moon. If, therefore, we conceive the moon's disc to be centrically superposed on that of Jupiter, not only would all the satellites be covered by it, but that which elongates itself most from the planet would not approach nearer to the moon's edge than one-sixth of its apparent diameter.

If all the satellites were at the same time at their greatest apparent distances from the planet, they would, relatively to

Fig. 7.



the apparent diameter of the planet, present the appearance represented in fig. 7.

By comparing their real diameters with their distances, the apparent diameters of the several satellites, as seen from Jupiter, may be easily ascertained.

18. The first satellite has an apparent diameter equal to that of the moon; the second and third are nearly equal and about half that diameter; and the apparent diameter of the other satellite is about the fourth part of that of the moon.

It may be easily imagined what various and interesting nocturnal phenomena are witnessed by the inhabitants of Jupiter, when the various magnitudes of these four moons are combined with the quick succession of their phases and the rapid apparent motions of the first and second.

The motions of the first three satellites are so related that they never can be at the same time on the same side of Jupiter; so that whenever any one of them is absent from the Jovian firmament at night, one at least of the others must be present. The nights are, therefore, always moonlit, except during eclipses, and often enlightened at once by three moons of different apparent magnitudes, and seen under different phases.

19. Of all the planets either of this or the terrestrial group, that which presents to the astronomical observer the most astonishing spectacle is Saturn—a stupendous globe, nearly 900 times greater in volume than the earth, surrounded by two, at least, and probably by several thin flat rings of solid matter, outside which revolve a group of eight moons; this entire system moving with a common motion so exactly maintained that no one part falls upon, overtakes, or is overtaken by another in their course around the sun.

Such is the SATURNIAN SYSTEM, the central body of which was known as a planet to the ancients, the annular appendages and satellites being the discovery of modern times.

The distance of Saturn from the sun is so enormous that if the whole earth's orbit, measuring nearly 200,000000 of miles in diameter, were filled with a sun, that sun seen from Saturn would be only about 24 times greater in its apparent diameter than is the actual sun seen from the earth. A cannon-ball moving at 500 miles an hour would take about 200 years; and a railway train moving 50 miles an hour would take about 2000 years to move from Saturn to the sun. Light, which moves at the rate of nearly 200000 miles per second, takes 1 hour 15 minutes to move over the same distance. Yet to this distance solar gravitation transmits its mandates, and is obeyed with the utmost promptitude and the most unerring precision.

Taking the diameter of Saturn's orbit at 1800,000000 of miles, its circumference is 5650,000000 of miles, over which it moves in 10759 days. Its daily motion is therefore 525140 miles, and its hourly 21880 miles.

20. All that has been said above respecting the atmosphere, the diurnal rotation, and their consequences, the clouds, atmospheric currents, trade-winds, and oblate figure in the case of Jupiter, may be applied without any important modification to Saturn.

This planet is attended by eight moons, four of which, like those of Jupiter, are remarkable for their proximity to the planet, three being at distances considerably less than that of the terrestrial moon from the earth, and the fourth at nearly the same distance. Of the four other moons, the most remote is ten times further from Saturn than the terrestrial moon is from the earth, and the nearest is about one half more distant.

The distances of moons are, however, more justly estimated relatively to the planets they attend, by expressing them in semi-diameters of the planet. If thus expressed, the moons of Saturn are on a scale ot distance very much less than that of the terrestrial moon. The distance of the most remote is 64 semi-diameters of Saturn, while that of the nearest is little more than 3 semi-diameters. The distance of the terrestrial moon from the earth is 60 semi-diameters.

Great, however, as these distances are, they are reduced to a very small apparent measure, owing to the remoteness of the Saturnian system from the earth. If the centre of the terrestrial moon were to come upon the centre of Saturn's disc, the most remote of his satellites could not approach nearer to the edge of the moon's disc than one-third of the moon's semi-diameter. Thus, although the Saturnian system fills a space measuring about 5,000000 of miles in its extreme breadth, this entire space would be covered by the moon's disc, even if that disc had a diameter one-third less than its actual diameter.

All that has been said of the phases and appearances of the moons of Jupiter, as presented to the inhabitants of that planet, is equally applicable to the satellites of Saturn, with this difference, that instead of four, there are eight moons continually revolving round the planet, and exhibiting all the monthly changes to which we are accustomed in the case of the solitary satellite of the earth.

The periods of Saturn's moons, like those of Jupiter, are short, with the exception of those most remote from the primary. The nearest passes through all its phases in 22½ hours, and the fourth, counting outwards, in less than 66 hours. The next three have months varying from 4 to 22 terrestrial days.

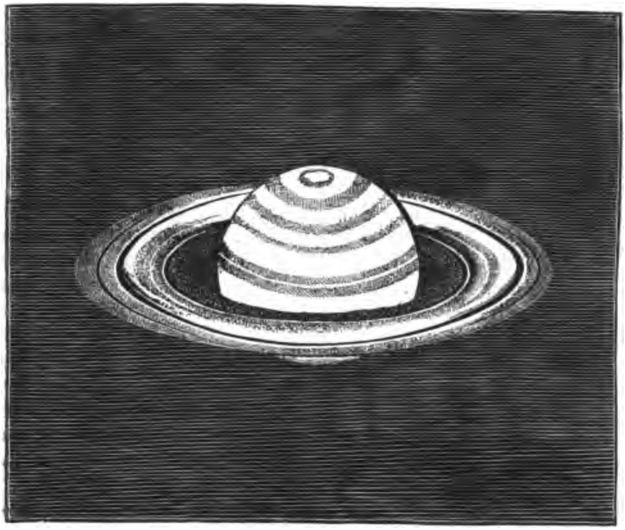
These seven moons move in orbits whose planes are nearly coincident with the plane of the Saturnian equator. The consequence of this arrangement is, that they are always visible by the inhabitants of both hemispheres when they are not eclipsed by the shadow of the planet.

The motion of the nearest moon is so rapid as to be perceivable by the Saturnians like that of the hour-hand of a colossal timepiece. It describes 360° in 22½ hours, being at the rate of 16° per hour, or 16′ per minute, so that in two minutes it moves over a space equal to the apparent diameter of the moon.

The eighth, or most remote satellite, is in many respects exceptional, and different from all the others. Unlike these, it moves in an orbit inclined at a considerable angle to the plane of the equator.

Owing to the great distance of Saturn, the dimensions of the satellites have not been ascertained. The sixth in order, proceeding outwards, called Titan, is, however, known to be the largest, and it appears certain that its volume is little less than that of the planet Mars. The three satellites immediately within this, Rhea, Dione, and Tethys, are smaller bodies, and can only be seen with telescopes of great power. The two nearest, Enceladus, and Mimas, require instruments of the very highest power and perfection, and atmospheric conditions of the most favourable nature, to be observable at all.

The real magnitudes of the satellites, the sixth excepted, being unascertained, nothing can be inferred with any certainty respecting their apparent magnitudes as seen from the surface of Saturn, except what may be reasonably conjectured upon analogies to other like bodies of the system. The satellites of Jupiter being all greater than the moon, while one of them exceeds Mercury in magnitude, and another is but little inferior in volume to that planet, it may be assumed with great probability of truth that the satellites of Saturn are at least severally greater in their actual dimensions than our moon.



SATURN,

AS SEEN IN NOVEMBER, 1852, WITH A REFRACTOR OF 6½ INCH APERTURE AT WATERINGBURY NEAR MAIDSTONE, BY W. R. DAWES.

THE PLANETS:

ARE THEY INHABITED WORLDS?

CHAPTER IV.

1. Apparent magnitudes of the moons as seen from Saturn.—2. Their phases—Short Saturnian months.—3. Solar and lunar eclipses.—4. Discovery of the rings.—5. Phases of the rings as seen from the earth.—6. Their appearance when seen edgeways in 1848—Schmidt's drawings of them.—7. Mountains upon them.—8. Their dimensions.—9. Discovery of the obscure semi-reflective rings.—10. Dawes' telescopic view of the planet and rings.—11. Appearance of the rings as seen from Saturn.—12. Errors committed on this subject by Bode, Herschel, Mädler, and others.—13. Correction of these errors.—14. Appearance of rings will vary with the latitude of the observer.—15. Illustrative diagrams.—16. Recapitulation.—17. No difficulty can arise in admitting the possibility of differently organised tribes on the different planets.—18. The sun, its physical character incompatible with habitability.—19. The moon not habitable.—20. Nor the satellites.—21. Comets not habitable.—22. The planetoids or asteroids.

1. If the estimate of the real magnitudes of the satellites, given at the conclusion of the last chapter, be admitted, their probable apparent magnitudes as seen from Saturn may be inferred from their distances. The distance of the first, Mimas, from the nearest part of the surface of the planet, is only 94,000 miles, or about 2½ times less than the distance of the moon; the distance of the second is about half that of the moon; that of the third about two-thirds, and that of the fourth about five-sixths, of the moon's distance. If these bodies, therefore, exceed the moon in their actual dimensions, their apparent magnitudes as seen from Saturn will exceed the apparent magnitude of the moon in a still greater ratio than that in which the distance of the moon from the earth exceeds their several distances from the surface of Saturn. Of the remaining satellites, little is as yet known of the seventh, Hyperion, which has only been recently discovered; and the great magnitude of the sixth, Titan, renders it probable that, notwithstanding its great distance, it may still appear to the Saturnians with a disc as great as that of the terrestrial moon.

2. All that has been observed respecting the remarkable appearances presented by the rapidly varying phases of Jupiter's moons is equally applicable to Saturn; the spectacle, however, being enriched and varied by twice the number of moons. Since the first satellite changes from the thinnest crescent to the half moon in five hours and a half (terrestrial), the gradual change of phase must be as visible as the motion of the hand of a timepiece. The second changes at a rate only one-half slower, that is, it passes from a thin crescent to the half moon in eight hours. The first passes from the state of the new to that of the full moon in eleven, and the second in sixteen hours. The interval between new and full moon for the third is twenty-two hours; for the fourth, thirty-two hours; for the fifth, fifty-three; for the sixth, eight terrestrial days; for the seventh, eleven; and for the eighth, forty.

3. The eclipses, solar and lunar, produced and suffered by these eight satellites are not so frequent and regular as those described as taking place in the Jovian system, because Saturn's equator is inclined to the sun's course at an angle of nearly 27°, considerably greater than the obliquity of the ecliptic, the consequence of which is that the sun, at and near the Saturnian midsummer and midwinter, departs to a great apparent distance from the equator, to which the motion of the satellites (except the eighth) is confined. For the same reason, the satellites depart further from the centre of the shadow, and all except the nearer ones generally move clear of the shadow in

opposition. The Saturnians, therefore, have the advantage over the Jovians of witnessing the frequently recurring spectacle of several full moons in their firmament.

4. The invention of the telescope having invested astronomers with the power of approaching, for optical purposes, hundreds of times closer to the objects of their observation, one of the earliest results of the exercise of this improved sense was the discovery that the disc of Saturn differed in a remarkable manner from those of the other planets in not being circular. It seemed at first to be a flattened oblong oval, approaching to the form of an elongated rectangle, rounded off at the corners. As the optical powers of the telescope were improved, it assumed the appearance of a great central disc, with two smaller discs, one at each side of it. These lateral discs, in fine, took the appearance of handles or ears, like the handles of a vase or jar, and they were accordingly called the ansæ of the disc, a name which they still retain. At length, in 1659, Huygens explained the true cause of this phenomenon, and showed that the planet is surrounded by a ring of opaque solid matter, in the centre of which it is suspended, and that what appear as ansæ are those parts of the ring beyond the disc of the planet at either side, which by projection are reduced to the form of the parts of an ellipse near the extremities of its greater axis, and that the open parts of the ansæ are produced by the dark sky visible through the space between the ring and the planet.

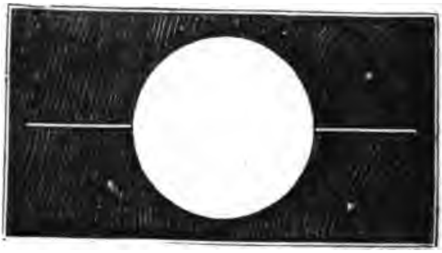
The improved telescopes, and greatly multiplied number and increased zeal and activity of observers, have supplied much more definite information as to the form, dimensions, structure, and position of this most extraordinary and unexampled appendage.

It has been ascertained that it consists of an annular plate of matter, the thickness of which is very inconsiderable compared with the superficies. It is nearly, but not precisely, concentric with the planet, and in the plane of its equator. This is proved by the coincidence of the plane of the ring with the general direction of the belts, and with that of the apparent motion of the spots by which the diurnal rotation of the planet has been ascertained.

When telescopes of adequate power are directed to the ring presented under a favourable aspect, dark streaks are seen upon its surface similar to the belts of the planet. One of these having been observed to have a permanence which seemed incompatible with the admission of the same atmospheric cause as that which has been assigned to the belts, it was conjectured that it arose from a real separation or division of the ring into two concentric rings placed one within the other. This conjecture was converted into certainty by the discovery that the same dark streak is seen in the same position on both sides of the ring. It has even been affirmed by some observers that stars have been seen in the space between the rings; but this requires confirmation. It is, however, considered as proved that the system consists of two concentric rings of unequal breadth, one placed outside the other, without any mutual contact.

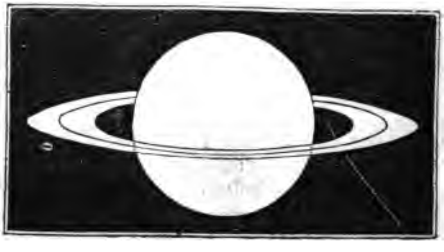
5. While the planet is carried round the sun in its orbital motion, the rings are presented to the view of observers situate on the earth under different aspects. In two positions of the planet at opposite points of its orbit the ring is seen edgeways, its plane then passing through the earth. It assumes these positions at intervals of about fifteen terrestrial years, or half a Saturnian year. If the ring were thick enough to be distinctly visible, and if its thickness were uniform, it would at these times have the appearance represented in fig. 1.

Fig. 1.



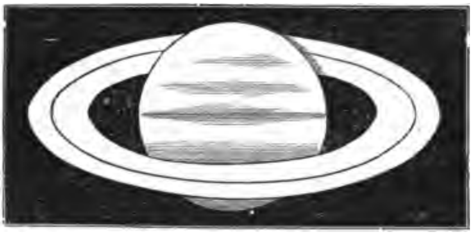
As it moves from these positions the rings become inclined at a sensible angle to the visual line, and this angle increasing from year to year, they appear more and more open, as represented in fig. 2; until, after an interval of 7½ years, or a quarter

Fig. 2.



of a Saturnian year, the plane of the rings forms the greatest possible angle, about 28°, with the visual line. At this time the appearance of the rings would be such as is represented in fig. 3.

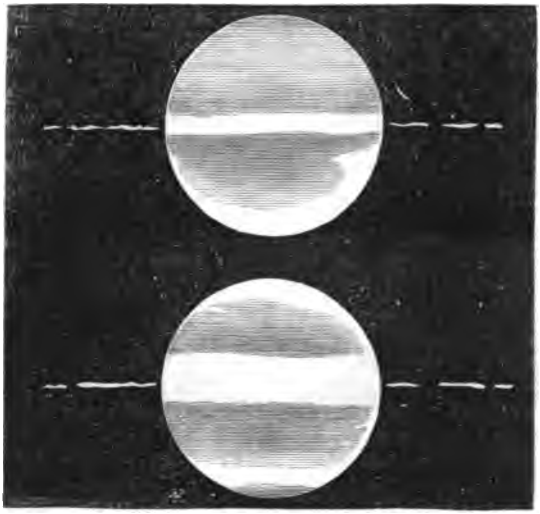
Fig. 3.



The times at which the rings are presented edgeways to the earth are very nearly identical with those of the Saturnian equinoxes. The last which took place was in 1848, and the next will consequently be in 1863.

6. In 1848, the ring being presented edgeways, some very interesting and curious observations were made upon it by

Figs. 4, 5.



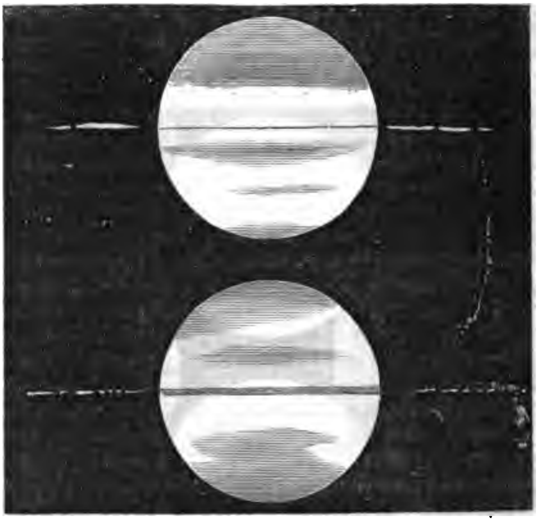
M. Julius Schmidt, at the Observatory at Bonn. It was found that the ring, instead of appearing as an even, thin line of light such as is represented in fig. 1, appeared as a broken and uneven line.

We have selected from the telescopic drawings made on that occasion by M. Schmidt, four, which are shown in Figs. 4, 5, 6, 7. These are intended only to represent the appearances of the edge of the rings, and not of the streaks on the disk of the planet.

Fig. 4 represents the ring as seen on the 26th June.
Fig. 5 ,, ,, ,, 3rd Sept.
Fig. 6 ,, ,, ,, 5th Sept.
Fig. 7 ,, ,, ,, 11th Sept.

7. This singular appearance must arise from great mountainous inequalities on the surface of the ring, rendering it much thicker at some parts than at others. At some parts it is too thin to be visible at Saturn's distance, while at the parts rendered thicker by lofty mountains, it is apparent.

Figs. 6, 7.



8. The breadth of the rings, as well as of the intervals which separate them from each other and from the planet, have been submitted to very precise micrometric observations; and the results obtained by different observers do not differ from each other by a fortieth part of the whole quantity measured. In the

following table are given the results of the micrometric observations of Professor Struve, reduced to the mean distance.

		Apparent Magnitude at mean Distance.	In Semi-diameters of the Planet.	Miles.
Semi-diameter of the planet . . .	*r*	8"·995	1·000	39,580
Exterior semi-diameter of exterior ring .	*a*	20·047	2·229	88,209
Interior do. do. . .	*a'*	17·644	1·961	77,636
Breadth of exterior ring	*a—a'*	2·403	0·268	10,573
Exterior semi-diameter of interior ring .	*b*	17·237	1·916	75,845
Interior do. do. .	*b'*	13·334	1·482	58,669
Breadth of interior ring	*b—b'*	3·903	0·434	17,176
Width of interval between the rings .	*a'—b*	0·407	0·045	1,791
Width of interval between planet and interior ring	*b'—r*	4·339	0·482	19,089
Breadth of the double ring, including interval	*a—b'*	6·713	0·747	29,540

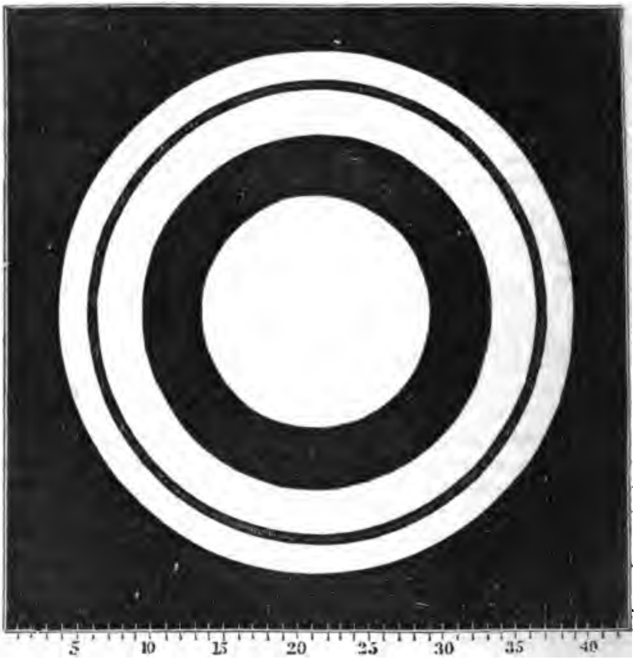
The relative dimensions of the two rings, and of the planet within them, are represented in fig. 8 projected upon the common plane of the rings and the planet's equator. Each division of the subjoined scale represents 5000 miles.

9. The most surprising result of recent telescopic observations of this planet has been the discovery of a ring, composed, as it would appear, of matter reflecting light much more imperfectly than the planet or rings already described; and, what is still more extraordinary, transparent to such a degree that the body of the planet can be seen through it.

In 1838, Dr. Galle, of the Berlin observatory, noticed a phenomenon, which he described as a gradual shading off of the inner ring towards the surface of the planet, as if the solid matter of the ring were continued beyond the limit of its illuminated surface, this continuation of the surface being rendered visible by a very feeble illumination, such as would attend a penumbra upon it; and measures of this obscure surface were published by him in the "Berlin Transactions" of that year.

The subject, however, attracted very little attention until towards the close of 1850, when Professor Bond, of Boston, and Mr. Dawes, in England, not only recognised the phenomenon noticed by Dr. Galle, but ascertained its character and features with great precision. The observations of Professor Bond were not known in England until the 4th of December; but the phenomenon was very fully and satisfactorily seen and described

Fig. 8.



by Mr. Dawes, on the 29th ot November. That astronomer, on the 3rd of December, called the attention of Mr. Lassell to it, who also witnessed it on that evening at the observatory of Mr. Dawes ; and both immediately published their observations and descriptions of it, which appeared in Europe simultaneously with those of Professor Bond.

It was not, however, until 1852 that the transparency was fully ascertained. From some observations made in September, Mr. Dawes strongly suspected its existence ; and about the same time it was clearly seen at Madras by Captain Jacob, and in October by Mr. Lassell at Malta, whither he had removed his observatory to obtain the advantages of a lower latitude and more serene sky. The result of these observations has been the conclusive proof of the unique phenomenon of a semi-transparent annular appendage to this planet.

10. The planet surrounded by this compound system of rings is represented at the head of this chapter. The drawing is reduced from the original sketch, made by Mr. Dawes. The principal division of the bright rings is visible throughout its entire circumference. The black line, supposed to be a division of the outer ring, is visible in the drawing of Mr. Dawes; but was not at all seen by Mr. Lassell.

A remarkably bright thin line, at the inner edge of the inner bright ring, was distinctly seen by Mr. Dawes in 1851 and 1852.

The inner bright ring is always a little brighter than the planet. It is not, however, uniformly bright. Its illumination is most intense at the outer edge, and grows gradually fainter towards the inner edge, where it is so feeble as to render it somewhat difficult to ascertain its exact limit. It would seem as if the imperfectly reflective quality there approaches to that of the obscure ring recently discovered. The open space between the ring and the planet has the same colour as the surrounding sky.

11. The rings must obviously form a most remarkable object in the firmament of Saturnian observers, and must play an important part in their uranography. The problem to determine their apparent magnitude, form, and position, in relation to the fixed stars, the sun, and Saturnian moons, has, accordingly, more or less engaged the attention of astronomers. It is nevertheless a singular fact that, although the subject has been discussed and examined by various authorities for three quarters of a century, the conclusions at which they have arrived, and the views which have been generally expressed and adopted respecting it, are completely erroneous.

12. In the Berlin *Jahrbuch* for 1786, Professor Bode published an essay on this subject, which, subject to the imperfect knowledge of the dimensions of the rings which had then resulted from the observations made upon them, does not seem to differ materially in principle from the views adopted by the most eminent astronomers of the present day.

Sir John Herschel, in his "Outlines of Astronomy," edit. 1849, states that the rings as seen from Saturn appear as vast arches spanning the sky from horizon to horizon, holding an almost invariable situation among the stars; and that, in the hemisphere of the planet which is on their dark side, a solar eclipse of fifteen years' duration takes place.

This statement, which has been reproduced by almost all writers both in England and on the continent, is incorrect in both the particulars stated. *First*, the rings do not hold an almost invariable position among the stars. On the contrary, their position with relation to the fixed stars is subject to a change so rapid that it must be sensible to Saturnian observers, the stars seen on one side of the rings passing to the other side from hour to hour. *Secondly*, no such phenomenon as a solar eclipse of fifteen years' duration, or any phenomenon bearing the least analogy to it, can take place on any part of the globe of Saturn.

Among the continental astronomers who have recently reviewed this question, the most eminent is Dr. Mädler, to whose observations and researches science is so largely indebted for the information we possess respecting the physical character of the surface of the Moon and Mars.

This astronomer maintains, like Herschel, that the rings hold a fixed position in the firmament, their edges being projected on parallels of declination, and that, consequently, all celestial objects are carried by the diurnal motion in circles parallel to them, so that in the same latitude of Saturn the same stars are always covered by the rings, and the same stars are always seen at the same distance from them.

This is also incorrect. The zones of the firmament covered by the rings are not bounded by parallels of declination, but by curves which intersect these parallels at various angles.

Dr. Mädler enters into elaborate calculations of the solar eclipses which take place during the winter half of the Saturnian year. He computes the duration of these various eclipses in the different latitudes of Saturn, and gives a table, by which it would appear that the solar eclipses which take place behind the inner ring vary in length from three months to several years, that the duration of the eclipses produced by the outer ring is still greater, and that the duration of the appearance of the sun in the interval between the rings varies in different latitudes from ten days to seven and eight months.*

These various conclusions and computations of Bode, Herschel, Mädler, and others, and the reasoning on which they are based, are altogether erroneous; and the solar phenomena which they describe have no correspondence with, nor any resemblance to, the actual uranographical phenomena.

13. The problem of the appearance of the system of rings in the Saturnian firmament, and their effect in occulting and eclipsing occasionally and temporarily the sun, the eight moons, and other celestial objects, was fully discussed, and, for the first time, definitely solved in a memoir by the author of

---

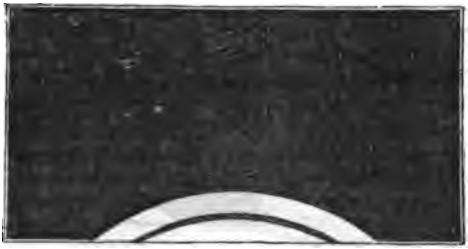
* See Populäre Astronomie, von Dr. J. H. Mädler. Beılin, 1852.

these pages, read to the Royal Astronomical Society in 1853, and published in the twenty-second volume of their "Transactions."

It is there demonstrated that the infinite skill of the Great Architect of the Universe has not permitted that this stupendous annular appendage, the uses of which still remain undiscovered, should be the cause of such darkness and desolation to the inhabitants of the planet, and such an aggravation of the rigours of their fifteen years' winter, as it has been inferred to be from the reasoning of the eminent astronomers already named, as well as many others, who have either adopted their conclusions, or arrived at like inferences by other arguments.

It is shown, on the contrary, that, by the apparent motion of the heavens, produced by the diurnal rotation of Saturn, the celestial objects, including, of course, the sun and the eight moons, are not carried parallel to the edges of the rings, as has been hitherto supposed; that they are moved so as to pass alternately from side to side of each of these edges; that in general such objects as pass under the rings are only occulted by them for short intervals before and after their meridional culmination; that although under some rare and exceptional circumstances and conditions, certain objects, the sun being among the number, are occulted from rising to setting, the continuance of such phenomenon is not such as has been supposed, and the places of its occurrence are far more limited. In short, it has no such character as would deprive the planet of any essential condition of habitability.

Fig. 9.



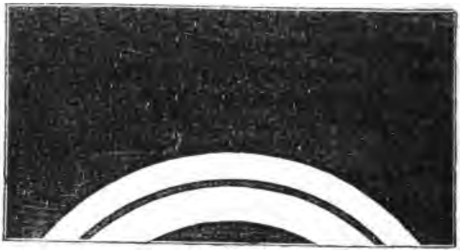
14. The appearance which the ring presents to the Saturnians must vary very much with the latitude of the observer and the season of the year. In the summer half-year, the observer and the sun being on the same side of the ring, it will present the appearance of an arch in the heavens, bearing some resemblance in its form to a rainbow, the surface, however, having an appearance resembling that of the moon.

The vertex or highest point of this arch will be upon his meridian, and the two portions into which it will be divided by the meridian will be equal and similar, and will descend to the horizon at points equally distant from the meridian. The apparent breadth of this illuminated bow will be greatest upon the meridian, and it will decrease in descending on either side towards the horizon, where it will be least. The division between the two rings will be apparent, and, except at places within a very short distance of the equator, the firmament will be visible through it.

The distance of the edge of the bow from the celestial equator will not be everywhere the same, as it has been erroneously assumed to be. That part of the bow which is upon the meridian will be most remote from the celestial equator; and in descending from the meridian on either side towards the horizon, the declination of its edge will gradually decrease, so that those points which rest upon the horizon will be nearer to the equator than the other points.

15. Some idea may be formed of the varieties of appearance presented by the ring to observers in different latitudes of the planet, by imagining an observer starting from that Saturnian pole which is on the same side of the ring as the sun, to travel along a meridian towards the equator. At first the convexity of the planet will intercept all view whatever of the ring, and this, as has been shown in the memoir already referred to, will continue until he has descended below the latitude 63° 20′ 38″. At this latitude the ring will just touch his horizon, and will continue to be more and more seen until he descends to latitude 47° 33′ 51″, when both rings will be seen as represented in fig. 9.

Fig. 10.



In descending to lower latitudes, more and more of the rings will rise above the horizon, and they will assume the form of a double bow, as represented in fig. 10.

As the observer descends lower and lower in latitude, the bow will take a higher and higher position, and will span a greater portion of the firmament, as represented in figs. 11, 12, 13.

It will be observed that, in all cases, the width of the bow decreases from the meridian to the horizon, and also decreases with the latitude of the observer.

Fig. 11.

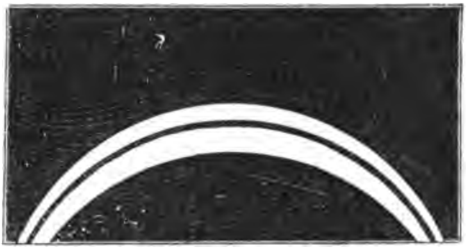


Fig. 12.

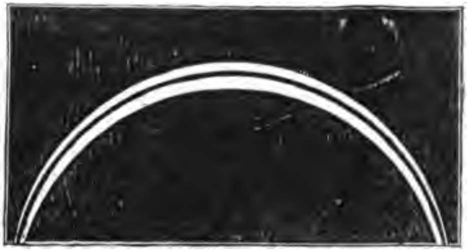
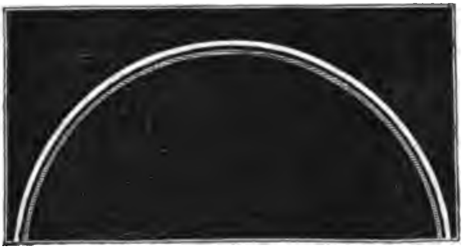


Fig. 13.



In fig. 14 is represented a portion of the ring, with the satellites as they appear above, showing different lunar phases.

We must refer those who may desire to pursue the Uranography of Saturn into its details to the memoir already cited, published in the "Transactions of the Royal Astronomical Society;" and to Chapter XV. of Dr. Lardner's "Astronomy."

Fig. 14.

16. We have thus presented the reader with a brief and rapid sketch of the circumstances attending the two chief groups of globes which compose the solar system, and have explained the numerous and striking analogies which, taken together, amount to a demonstration that, in the economy of the material universe, these globes must subserve the same purposes as the earth, and must be the dwellings of tribes of organised creatures, having a corresponding analogy to those which inhabit the earth.

17. The differences of organisation and character which would be suggested as probable or necessary by the different distances of the several planets from the common source of light and heat, and the consequent differences of intensity of these physical agencies upon them, by the different weights of bodies on their surfaces, owing to the different intensities of their attractions on such bodies; by the different intervals which mark the alternations of light and darkness; are not more than are seen to prevail among the organised tribes, animal and vegetable, which inhabit different regions of the earth. The animals and plants of the tropical zones differ in general from those of the temperate and the polar zones; and even in the same zone we find different tribes of organised creatures flourish, at different elevations above the level of the sea. There is nothing more wonderful than this in the varieties of organisation suggested by the various physical conditions by which the planets are affected.

But these arguments and analogies will acquire great additional force, when it is shown that the other bodies composing the solar system are not furnished with like provisions, and exhibit none of the fitness, for the dwelling-places of such tribes.

18. The Sun, as will be shown in another part of this series, is a vast globe, invested with an ocean, or rather an atmosphere, of flame, in which the most astonishing convulsions and eruptions

are continually manifested. Here is no moderated and regulated temperature, no alternations of light and darkness, no succession of seasons, no varieties of climate, no divisions of land and water. The sun is, in fact, a vast globular furnace, the heat emitted from each square foot of which is seven times greater than the heat which issues from a square foot of the fiercest blast furnace. Such is the intensity of this heat, that although the distance of the earth from the sun is little less than 100,000000 of miles, and although the surface of the earth, by reason of its diurnal rotation, is withdrawn from the sun's direct influence during alternate intervals of twelve hours, yet the total quantity of heat received by the earth from the sun in a year is sufficient, if uniformly diffused over its surface, to liquefy a crust of ice covering it 100 feet thick!

It follows from this that the average heat received by each square foot of the earth's surface from the sun in a year would be sufficient to dissolve 5400 lbs. weight of ice.

How entirely removed from all analogy with the earth such a globe of fire must be, is apparent.

19. The moon, on the other hand, while it has nothing in common with the sun, is not the less destitute of all those analogies to the earth which suggest habitability. We shall, on another occasion, explain fully the circumstances attending our satellite. For the present, it will be sufficient to observe that it has no atmosphere, no clouds, no water or other liquids, no intervals of light and darkness, bearing any analogy to our days and nights; that its surface bristles with one unbroken continuity of rugged mountainous region more savage than the glaciers which crown the summits of the Alps, the Andes, or the Cordilleras, and that even in the valleys a temperature must prevail colder than that of our poles.

It will therefore be easily imagined how little analogy such a globe has to the earth, and how utterly unsuited it would be for the habitation of organised tribes.

20. Astronomical observation renders it probable that the satellites of the other planets are under physical conditions similar to that of the moon, and that, like the moon, they are deprived of the conditions of habitability.

21. A numerous class of bodies, called comets, have been proved by modern observation to be connected by gravitation with the solar system. These bodies appear generally to be divested of all solidity, and to be masses of vaporous matter floating through the system. It is obvious that these can have no analogy to the earth.

In the space between the two groups of planets which present such striking analogies to the earth, another group consisting of six or seven-and-twenty bodies, circulate round the sun, as represented in the plan of the system given in this tract, Chap. II., fig. 1. The number of these is augmented every year by the discovery of some which were not before seen.

22. These bodies, which have been called PLANETOIDS or ASTEROIDS, obey the law of gravitation in their motion round the sun. Their distances from that luminary are not only different one from another, but they differ from all the other planets in their extremely small magnitude. In the telescope they are seen as stars of the tenth or twelfth magnitude, and their real magnitudes are so minute that they have never yet been certainly ascertained, notwithstanding the number and power of the telescopes that have been directed to them.

As to their origin, and the parts they play in the economy of creation, nothing can be offered but the most vague and uncertain conjecture. According to the opinion of some, they are the minute fragments of a single planet, which has been smashed to pieces by collision with the solid nucleus of a comet, assuming the possible existence of such a body. According to others, the fracture may have been produced by internal explosion, arising from causes similar to those which produce earthquakes and volcanic phenomena. Others again reject altogether the hypothesis of the fracture of a formerly existing planet, and substitute for it the contrary hypothesis, that these numerous minute bodies are the germs or constituent elements of a future planet, which will be formed by these bodies gradually coalescing into one globe, some of them, perhaps, assuming the character of satellites to it.

These are speculations which, however ingenious and attractive, are beside our present purpose. It is plain that the planetoids, as they now actually exist, present none of the analogies to the earth which are so conspicuous in the other planets.

MR. BISHOP'S OBSERVATORY, REGENT'S PARK, MEMORABLE BY THE DISCOVERY THERE OF ELEVEN PLANETS.

THE NEW PLANETS.

1.—Discovery of these planets.—2. The old planets.—3. Numerical law of their distances.—4. A missing planet.—5. Conjecture of Professor Bode.—6. Discovery of Ceres.—7. Of Pallas.—8. Theory of Dr. Olbers—a broken planet.—9. Discovery of Juno.—10. Of Vesta.—11. Rapid discovery of the others.—12. Table of the group.—13. Circumstances corroborating the theory of Dr. Olbers.—14. Amateur astronomers.—15. Minute bulk of these planets.—16. Corroboratory of Dr. Olbers' theory.—17. Force of gravity upon them.

1. WITHOUT being astronomers, every one who reads the newspapers must be familiar with the fact, that within the last few years a multitude of small planets has been discovered, which, notwithstanding the vigilance and sagacity of observers, in various parts of Europe, had hitherto escaped notice. As the circumstances attending and preceding this extraordinary mass of astronomical discovery are novel and interesting, we propose at present to bring them before our readers.

2. Almost every one who knows anything beyond the limits of the most ordinary education, is aware that the solar system, as it was known until the last hundred years, consisted of six planets, which, proceeding outwards from the sun, received the mythological names of Mercury, Venus, the Earth or Tellus, Mars, Jupiter, and Saturn. It is now about three-quarters of a century since the late Sir William Herschel added one to this number, by the discovery of the planet since called Uranus, revolving outside the orbit of Saturn.

3. On comparing the successive distances of these several planets from the sun, it was observed by Kepler, that a remarkable numerical harmony prevailed among them. Thus, if we begin from the nearest planet to the sun, Mercury, and measure the intervals between planet and planet proceeding outwards, it will be found that each successive interval is almost exactly double the one before, subject, nevertheless, to a striking exception in the case of the interval between Mars and Jupiter.

4. Although this remarkable arithmetical harmony was not fulfilled with that numerical precision which characterises some other astronomical laws, there was, nevertheless, so striking an approximation to it as to produce a strong impression, that it must be founded upon some physical cause, and not merely accidental. The near approximation to its exact fulfilment, supplied grounds for a very reasonable conjecture, that a planet was wanting in the system, whose position between Mars and Jupiter would be such as to fill the vacant place in the progression of distances.

To show how strong the analogy was in favour of such a supposition, we have placed in the following table the succession of calculated distances from Mercury's orbit, which will exactly fulfil it, in juxtaposition with the actual distances of the planets, the earth's distance from the sun being the unit.

	Calculated distance from Mercury.	Actual distance from Mercury.
Venus . . .	0·3362	0·3362
Earth	0·6724	0·6129
Mars . . .	1·3448	1·1366
Absent planet . .	2·6896	
Jupiter . . .	5·3792	4·8157
Saturn . . .	10·7584	9·1517
Uranus . . .	21·5168	18·7953

By comparing these numbers, it will be apparent, that although the succession of distances does not correspond precisely with a numerical series in duple progression, there is nevertheless a certain approach to such a series, and at all events a glaring breach of continuity between Mars and Jupiter.

5. Towards the close of the last century, Professor Bode, of Berlin, revived this question of a deficient planet, and gave the numerical progression which indicated its absence in the form in which it has just been stated; and an association of astronomers was formed under the auspices of the celebrated Baron de Zach, of Gotha, to organise and prosecute a course of observation, with the special purpose of searching for the supposed undiscovered member of the solar system. The very remarkable results which have followed this measure, the consequences of which have not even yet been fully developed, will presently be apparent.

6. On the first day of the present century, Professor Piazzi observing in the fine serene sky of Palermo, noticed a small star of about the 7th or 8th magnitude which was not registered in the catalogues. On the night of the 2nd Jan. again observing it, he found that its position relative to the surrounding stars was sensibly changed. The object appearing to be invested with a nebulous haze, he took it at first for a comet, and announced it as such to the scientific world. Its orbit being, however, computed by Professor Gauss, of Göttingen, it was found to have a period of 1652 days, and a mean distance from the sun expressed by 2·735, that of the earth being 1.

By comparing this distance with that given in the preceding table at which a planet was presumed to be absent, it will be seen that the object thus discovered filled the place with striking arithmetical precision.

Piazzi gave to this new member of the system the name CERES.

7. Soon after the discovery of Ceres, the planet passing into conjunction ceased to be visible. In searching for it after emerging from the sun's rays in March, 1802, Dr. Olbers noticed on the 28th a small star in the constellation of Virgo, at a place which he had examined in the two preceding months, and where he knew that no such object was *then* apparent. It appeared as a star of the seventh magnitude, the smallest which is visible without a telescope. In the course of a few hours he found its position visibly changed in relation to the surrounding stars. In fine, the object proved to be another planet, bearing a striking analogy to Ceres, and what was then totally unprecedented in the system, moving in an orbit at very nearly the same mean distance from the sun, and having, therefore, nearly the same period.

Dr. Olbers called this planet PALLAS.

8. This circumstance, combined with the exceptional minuteness of these two planets, suggested to Olbers the startling, and then, as it must have appeared, extravagantly improbable hypothesis, that a single planet of the ordinary magnitude existed formerly at the distance indicated by Bode's analogy,—that it was broken into small fragments either by internal explosion from some cause analogous to volcanic action, or by collision with a comet,—that Ceres and Pallas were two of its fragments, and in fine, that it was very likely that many other fragments, smaller still, were revolving in similar orbits, many of which might reward the labour of future observers who might direct their attention to these regions of the firmament.

In support of this curious conjecture, it was urged that in the case of such a catastrophe as was involved in the supposition, the fragments, according to the established laws of physics, would necessarily continue to revolve in orbits, not differing much in their mean distances from that of the original planet; that the obliquities of the orbits to each other and to that of the original planet might be subject to a wider limit; that the eccentricities might also have exceptional magnitudes; and, finally, that such bodies might be expected to have magnitudes so indefinitely minute as to be out of all analogy or comparison, not only with the other primary planets, but even with the smallest of the secondary ones.

Ceres and Pallas were both so small as to elude all attempts to estimate their diameters, real or apparent. They appeared like stellar points with no appreciable disk, but surrounded with a nebulous haziness, which would have rendered very uncertain any measurement of an object so minute. Sir W. Herschel thought that Pallas did not exceed 75 miles in diameter. Others have admitted that it might measure a few hundred miles. Ceres is still smaller.

The obliquity of the orbit of Ceres to the plane of the ecliptic is above 10½°, and that of Pallas more than 34½°. Both planets, therefore, when most remote from the ecliptic pass far beyond the limits of the zodiac, and differ in obliquity from each other by a quantity far exceeding the entire inclination of any of the older planets.

It was further observed by Dr. Olbers, that at a point near the descending node of Pallas, the orbits of the two planets very nearly coincided.

Thus it appeared that all the conditions which rendered these bodies exceptional, and in which they differed from the other members of the solar system, were precisely those which were consistent with the hypothesis of their origin advanced by Dr. Olbers.

9. A year and a half elapsed before any further discovery was produced to favour this hypothesis. Meanwhile, observers did not relax their zeal and their labours, and on Sept. 1, 1804, at ten o'clock, P.M., Professor Harding, of Lilienthal, discovered another minute planet, which observation soon proved to agree in all its essential conditions with the hypothesis of Olbers, having a mean distance very nearly equal to those of Ceres and Pallas, an exceptional obliquity of 13°, and a considerable eccentricity.

This planet was named JUNO.

Juno has the appearance of a star of the 8th magnitude, and a reddish colour. It was discovered with a very ordinary telescope, of 30 inches focal length and 2 inches aperture.

10. On the 29th of March, 1807, Dr. Olbers discovered another planet, under circumstances precisely similar to those already related in the cases of the former discoveries. The name VESTA was given to this planet, which, in its minute magnitude, and the character of its orbit, was analogous to Ceres, Pallas, and Juno.

Vesta is the brightest, and, apparently, the largest of all this group of planets; and, when in opposition, may be sometimes distinguished by good and practised eyes without a telescope. Observers differ in their impressions of the colour of this planet. Harding and other German observers consider her to be reddish; others contend that she is perfectly white. Mr. Hind says that he has repeatedly examined her under various powers, and always received the impression of a pale yellowish cast in her light.

11. The labours of the observers of the beginning of the century having been now prosecuted for some years without further results, were discontinued; and it is probable that but for the admirable charts of the stars which have been since published, no other members of this remarkable group of planets would have been discovered. These, however, containing all the stars up to the 9th or 10th magnitude, included within a zone of the firmament 30° in width, extending to 15° on each side of the celestial equator, supplied so important and obvious an instrument of research, that the subject was again resumed, with a better prospect of successful results. It was only necessary for the observer, map in hand, to examine, degree by degree, the zone within which such bodies are known to move, and to compare, star by star, the heavens with the map. When a star is observed which is not marked on the map, it is watched from hour to hour, and from night to night. If it do not change its position, it must be inferred that it has been omitted in the construction of the map, and it is marked upon it

in its proper place. If it change its position, it must be inferred to be a planet, and its orbit is soon calculated from its observed changes of position.

By these means M. Hencke, an amateur observer of Driesen in Prussia, discovered, on the 8th December, 1845, another of the small planets, which has been named ASTRÆA.

This discovery was the signal for an extraordinary start. It had so happened that within some years several private observatories had been established, and a most respectable, intelligent, and wealthy body of amateurs and volunteers has been added to the regular professional astronomical corps. The result of this is, that within a few years a most unexpected number of planets has been discovered, all occupying nearly the same place in the system; thus, three were discovered in 1847, one in 1848, one in 1849, three in 1850, two in 1851, eight in 1852, four in 1853, and six in 1854, and one on the 6th April, 1855,—making the total number discovered to the date of writing these lines (1st May, 1855) thirty-four.

12. A tabular statement of the elements of these planets was published in the "Annuaire du Bureau des Longitudes" at Paris for the present year, 1855, by M. Le Verrier and his assistants. Recently, however, a much more complete table has been published by Mr. Bishop, whose observatory in the Regent's Park has been signalised by the discovery of eleven of these thirty-four bodies. Desiring to give as wide circulation as possible to this mass of interesting astronomical data, I would refer the reader to Mr. Bishop's table, from which I have extracted the one annexed to this notice.

To facilitate such researches, Mr. Bishop and his assistants commenced in the winter of 1846-7 the preparation of a series of charts, including all stars to those of the eleventh magnitude, within 3° of the ecliptic. "At the present moment," says Mr. Bishop, writing in March, 1855, "fourteen maps are finished, engraved, and published to assist other observers in their search for new planetary bodies, and it is hoped to place the others before the public with no great delay." It was in the preparation of these charts, aided by those of Berlin, that ten planets were discovered at Mr. Bishop's observatory by Mr. Hind, and the eleventh more recently by Mr. Marth.

Mr. Bishop remarks, that during the preparation of his maps several other planets were seen, but lost again through the long-continuance of unfavourable weather, or owing to the object not having been missed at a sufficiently early period after it was entered upon the map.

Too much credit cannot be given to various astronomers, amateur as well as professional, for the spirit and perseverance with which they have undertaken the preparation of these Zodiacal Stellar Charts. Mr. Cooper of Sligo, and his assistant Mr. Graham, are understood to be thus occupied. They have already published three volumes containing the approximate positions of more than 45000 stars. Professor De Gasparis, of Naples, and Mr. Chacornac, of Paris, are similarly engaged.

In further illustration of the table annexed to this notice, Mr. Bishop adds the following observations:—

The *fourth* column contains the estimated magnitude or degree of brightness of each planet at the time of discovery. It would appear that the four which attain the highest degree of brilliancy are Vesta (often visible without a telescope), Pallas, Iris, and Flora.

The *fifth* column gives the mean longitude for noon, Greenwich time, on the 1st of January, 1855, reckoned from the equinox of that date.

In the *sixth* is found the longitude of the perihelion, or nearest point of approach of each planet to the sun, as viewed from that luminary.

The *seventh* contains the position of the ascending node, or the point in the ecliptic where the planet passes from south to north latitude, as viewed from the sun.

The *eighth* shows the inclination of each orbit to the ecliptic, or the angle between the planes of the paths of the earth and planet. It will be remarked that Pallas, Euphrosyne, and Phocea, have the largest inclinations, while Massilia and Themis exhibit the least; or, in other words, revolve nearly in the ecliptic.

The *ninth* column expresses the amount of excentricity or deviation from the circle. It varies from 0·075 in the case of Amphitrite to 0·346 in that of Polyhymnia.

The *tenth* gives the mean daily sidereal motion, or the space through which each planet would move in one day, if it described a circle round the sun with its average velocity. The numbers in this column multiplied by the periods expressed in days will, therefore, be equal to the circumference, or 360°.

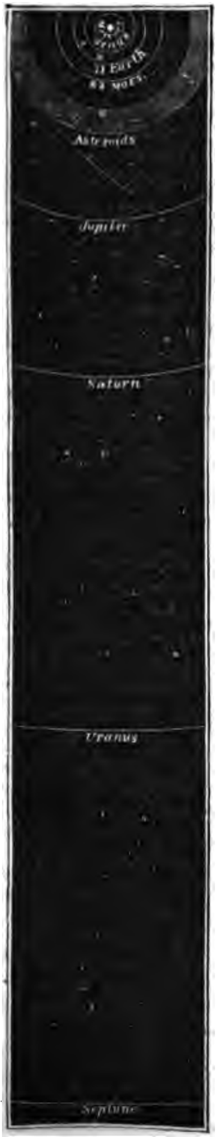
The *eleventh* shows the mean distances from the sun, or the semi-axes major of the orbits, expressed in units of the earth's average distance from that body, and carried to two places of decimals. Flora has the least, and, according to the table, Euphrosyne the greatest; though the recent date of this planet's discovery, and consequent comparatively short extent of observation, leaves us in a little uncertainty whether its mean distance will ultimately be found to exceed that of Hygeia or Themis.

The *twelfth* shows the length of the sidereal revolution in days. The periods vary from 1193 days, that of Flora, to 2048 days, which is that of Euphrosyne; the difference amounting to 855 days, or 2⅓ years.

I have annexed to the table the thirty-fourth and thirty-fifth planets discovered by Mr. Chacornac and M. Luther since Mr. Bishop's table was printed. The elements of the last of these objects, however, have not yet been determined.

13. In their exceptional minuteness of volume, their mean distances from the sun, and the very variable obliquities and eccentricities of their orbits, they all resemble the first four dis-

Fig. 1.



covered in the beginning of the century, and are therefore in complete accordance with the conditions mentioned in the curious hypothesis of Olbers above stated.

The planet discovered by M. Gasparis, on the 17th of March, 1852, was observed by that astronomer at the Naples Observatory, on the 17th, 19th, and 20th March. It appeared as a star of the 10th or 11th magnitude. The observations were published in the "Comptes Rendus," of the Academy of Sciences, Paris, tome xxxiv. p. 532.

The planet discovered by M. Luther was observed by that astronomer at Bilk, near Dusseldorf, on the 17th April, and again by M. Argelander, on the 22d April, at Bonn. The observations were published in the "Comptes Rendus" of the Paris Academy, tome xxxiv. p. 647.

14. Dr. Olbers was a practitioner in medicine, Messrs. Hencke, Luther, and Goldschmidt amateur observers, Mr. Hind has been engaged in the private observatory of Mr. Bishop, in the Regent's Park, and Mr. Graham in that of Mr. Cooper, at Markree, in the county of Sligo, in Ireland. It appears, therefore, that of these twenty-three members of the solar system the scientific world owes no less than fourteen to amateur astronomers, and observatories erected and maintained by private individuals, totally unconnected with any national or public establishments, and receiving no aid or support from the state. Mr. Hind has obtained for himself the honourable distinction which must attach to the discoverer of ten of these bodies. Five are due to M. de Gasparis, assistant-astronomer at the Royal Observatory at Naples.

M. Hermann Goldschmidt is an historical painter, a native of Frankfort-on-the-Maine, but resident for the last eighteen years in Paris. He discovered the planet with a small ordinary telescope, placed in the balcony of his apartment, No. 12, Rue de Seine, in the Faubourg St. Germain.

15. By inspecting the above table, it will be seen that these thirty-three planets move within a region of the solar system comprised between 2·2 and 3·2 times the mean distance of the earth. Their magnitudes are too minute to be ascertained with any degree of precision and certainty by any means of measurement hitherto discovered, and it may be inferred, with great probability, that they do not in general exceed 100 miles, that is, the 80th part of the diameter of the earth. Assuming, then, such to be their mean dimensions, and considering that the bulk of globes is in the proportion of the cubes of their diameters, it would follow, that, to make a globe as large as the earth, it would be necessary that 512000 such planets as these should be rolled into one.

16. It will not fail to be observed, what great probability this extreme minuteness of bulk, combined with the circumstance of their being all so nearly at the same distance from the sun, gives to the hypothesis of Dr. Olbers.

To show the relative position of this group of planets and those of the larger members of the system, we have represented in fig. 1, in their proper proportions, the successive distances of the planets from the sun, the place of these new planets being indicated by the band of parallel circles drawn in close proximity.

Being distinguished from the other planets of the system by so many singular circumstances, some astronomers denominated these bodies Asteroids; we think, however, that, for reasons that must be obvious, the name Planetoids would be preferable.

17. From the minuteness of their masses, the force of gravity on the surface of these bodies must be very inconsiderable; and this would account for a circumstance which has been observed on some of them, namely, that their atmospheres are relatively much more extensive than those of the larger planets, since the same mass of air, feebly attracted, would dilate into a volume comparatively enormous. Muscular power would be more efficacious on them in the same proportion; thus, a man might spring upwards through sixty or eighty perpendicular feet, and return to the ground, sustaining no greater shock than would be felt upon the earth in descending from the height of two or three feet. "On such planets," observes Herschel, "giants might exist, and those enormous animals which on earth require the buoyant power of water to counteract their weight."

THE NEW PLANETS.

Name of Planet.	Date of discovery.	Discoverer.	Magnitude.	Mean Longitude, 1855, Jan. 1, at noon.	Longitude of Perihelion.	Long. of ascending node.	Inclination of orbit to the Ecliptic.	Eccentricity.	Mean daily sidereal motion.		Mean distance from the Sun (Earth's as unity).	Sidereal revolution in days.
	18			°	°	°	°		'	"		
Ceres	01 Jan.	Piazzi	8	340	150	81	11	0·08	12	51	2·77	1680
Pallas	02 Mar.	Olbers	7	319	122	173	35	0·24	12	49	2·77	1686
Juno	04 Sept.	Harding	8	210	54	171	13	0·26	13	34	2·67	1592
Vesta	07 Mar.	Olbers	7	250	251	103	7	0·09	16	17	2·36	1326
Astræa ...	45 Dec.	Hencke	9	157	136	142	5	0·19	14	18	2·58	1511
Hebe	47 July	Hencke	9	283	15	139	15	0·20	15	39	2·43	1380
Iris	47 Aug.	Hind	9	336	41	260	5	0·23	16	3	2·39	1346
Flora	47 Oct.	Hind	9	121	33	110	6	0·16	18	6	2·20	1193
Metis	48 Apr.	Graham	10	147	72	69	6	0·12	16	2	2·39	1347
Hygeia ...	49 Apr.	Gasparis	9	207	228	288	4	0·10	10	35	3·15	2041
Parthenope	50 May	Gasparis	9	317	317	125	5	0·10	15	24	2·45	1402
Victoria ...	50 Sept.	Hind	8	51	302	236	8	0·22	16	35	2·33	1300
Egeria......	50 Nov.	Gasparis	9	46	120	43	17	0·09	14	17	2·58	1512
Irene	51 May „ May	Hind Gasparis	9	178	179	87	9	0·17	14	14	2·59	1518
Eunomia ...	51 July	Gasparis	9	234	28	294	12	0·19	13	46	2·64	1570
Psyche......	52 Mar.	Gasparis	10	347	13	151	3	0·13	11	50	2·92	1825
Thetis	52 Apr.	Luther	10	94	259	125	6	0·13	15	12	2·47	1421
Melpomene	52 June	Hind	9	199	15	150	10	0·22	17	0	2·30	1271
Fortuna ...	52 Aug.	Hind	9	209	31	211	2	0·16	15	29	2·44	1395
Massilia ...	52 Sept. „ Sept.	Gasparis Chacornac	9	237	98	207	1	0·15	15	50	2·41	1364
Lutetia ...	52 Nov.	Goldschmidt	9	231	327	81	3	0·16	15	34	2·44	1388
Calliope ...	52 Nov.	Hind	9	222	59	67	14	0·10	11	53	2·91	1817
Thalia......	52 Dec.	Hind	10	258	123	68	10	0·24	13	54	2·63	1554
Themis ...	53 Apr.	Gasparis	12	279	135	36	1	0·12	10	36	3·14	2037
Phocea ...	53 Apr.	Chacornac	9	51	303	214	22	0·25	15	54	2·40	1359
Proserpine	53 May	Luther	11	357	236	46	4	0·09	13	40	2·66	1581
Euterpe ...	53 Nov.	Hind	9	175	88	94	2	0·17	16	27	2·35	1311
Bellona ...	54 Mar.	Luther	10	224	122	145	9	0·15	12	48	2·78	1689
Amphitrite	54 Mar. „ Mar. „ Mar.	Marth Pogson Chacornac	10	255	57	356	6	0·07	14	29	2·55	1491
Urania ...	54 July	Hind	9	10	31	308	2	0·17	16	0	2·39	1350
Euphrosyne	54 Sept.	Ferguson	10	54	94	31	26	0·22	10	33	3·16	2048
Pomona ...	54 Oct.	Goldschmidt	11	55	209	221	6	0·08	14	17	2·58	1512
Polyhymnia	54 Oct.	Chacornac	10	22	340	9	2	0·35	12	5	2·88	1787
———	55 Apr.	Chacornac	11	350	188	184	5	0·07	13	41	2·65	1574
Leucothea	55 Apr.	Luther										

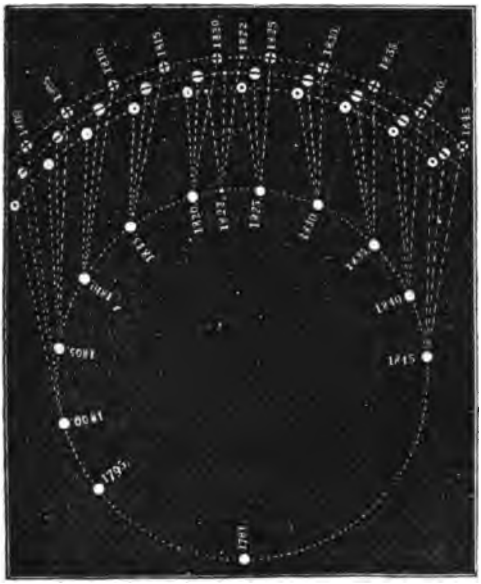


Fig. 4.

LE VERRIER AND ADAMS' PLANET.

1.—Surprise excited by the discovery.—2. How a body may be discovered without seeing it.—3. Generalisation of the principle.—4. Its application to the case of Neptune.—5. Condition of the solar system before the discovery.—6. Observed disturbances of Uranus.—7. Great regularity of these effects.—8. How they would be produced by a more distant planet.—9. Calculations of Le Verrier and Adams.—10. Elements of the sought planet according to these geometers.—11. Its actual discovery.—12. Its corrected elements.—13. Discrepancies between the actual and predicted elements explained.—14. Comparison of the effects of the real and predicted planets.—15. The discovery not to be ascribed to chance.—16. The period ot Neptune computed.—17. Computation of his distance.—18. Its prodigious orbital motion.—19. Illustrated by a railway train.—20. Its magnitude.—21. Its satellite.—22. Its weight.—23. Its bulk.—24. The sun's light and heat upon it.—25. The sun's apparent diameter seen from it.—26. Its suspected ring.

1. The universal astonishment which was excited some years ago by the announcement that certain astronomers, whose names

till then were but little known in the scientific world, and not at all to the general public, had discovered the existence of a new planet, without ever having seen it themselves, and without its having been seen by any one else, will not be soon forgotten.

2. Nevertheless, a little reflection will show that there was not so much cause for surprise in such a discovery, as there might at first appear to be; the only cause of the surprise must depend upon the supposition, that the existence of such a body could only be ascertained by the immediate evidence of the eye directed upon it; but surely cases without number will suggest themselves to every one, in which not only the existence of bodies, but their haunts, are ascertained otherwise than by seeing them. The sportsman goes forth, attended by his hounds, in pursuit of the fox; the existence of the game is ascertained by the scent of the hounds, without seeing it, and possibly at a long distance from the place where it lies; by following closely the scent which it has left upon its track, its place of concealment is soon attained, and the game is started.

3. If we generalise the principles suggested by this familiar illustration, we shall find that it amounts to this, that the existence of a body, and the place at which it is to be found, can be ascertained with as much certainty and precision, by closely observing the peculiar effects which that body produces upon other bodies upon which it acts, and by tracing these effects, as if we actually saw the body we are in quest of. It is the peculiar nature of the fox to leave upon the ground on which he treads an odour which characterises him. The organs of the hound are so constituted as to be highly susceptible of being affected by this odour, and a sufficient number of these animals being started over the ground, they are trained to seek for the scented track, and when found to follow it. The game is thus discovered, not by the sense of sight, but by the effects which it has produced upon other bodies, which themselves affect a different sense.

4. Now let us suppose it possible, that a planet moving through the universe, which was never seen by any observer, should produce upon other planets, which are seen and observed, certain effects; that these effects can be seen and ascertained by astronomers, and that the said astronomers can infer from the general principles of their peculiar science, that these effects are such as could only be produced by a planetary body, moving at a given time in a given direction; such effects would, in that case, prove the existence of a planet, even though it were never seen. What the scent is to the hound, these effects are to the not less sagacious instincts of the astronomer.

Such then were in fact the means by which the discovery of the planet, since called Neptune, was made; a discovery which was incontestably one of the most signal triumphs ever attained by mathematical science, and which marked an era that must be for ever memorable in the history of physical investigation.

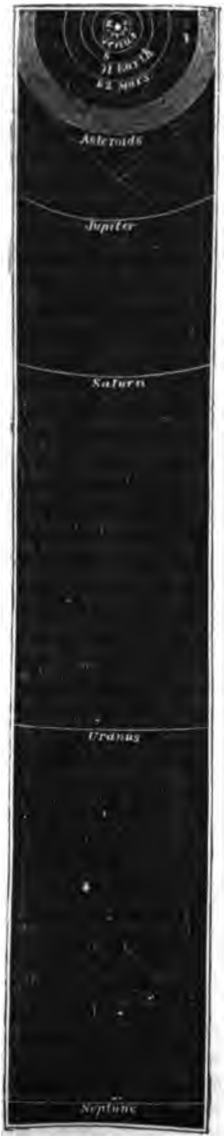
If the planets were subject only to the attraction of the sun, they would revolve in exact ellipses, of which the sun would be the common focus; but being also subject to the attraction of each other, which, though incomparably more feeble than that of the presiding central mass, produces sensible and measurable effects, consequent deviations from these elliptic paths, called PERTURBATIONS, take place. The masses and relative motions of the planets being known, these disturbances can be ascertained with such accuracy, that the position of any known planet at any epoch, past or future, can be determined with the most surprising degree of precision.

If, therefore, it should be found, that the motion which a planet is observed to have is not in accordance with that which it ought to have, subject to the central attraction of the sun, and the disturbing actions of the surrounding planets, it must be inferred that some other disturbing attraction acts upon it, proceeding from an undiscovered cause, and, in this case, a problem novel in its form and data, and beset with difficulties which might well appear insuperable, is presented to the physical astronomer. If the solution of the problem, to determine the disturbances produced upon the orbit of a planet by another planet, whose mass and motions are known, be regarded as a stupendous achievement in physical and mathematical science, how much more formidable must not the converse question be regarded, in which the disturbances are given to find the planet.

Such was, nevertheless, the problem of which the discovery of Neptune has been the astonishing solution.

Although no exposition of the actual process by which this great intellectual achievement has been effected, could be comprehended without the possession of an amount of mathematical knowledge far exceeding that which is expected from the readers of works much less elementary than the present, we may not be altogether unsuccessful in attempting to illustrate the principle on which an investigation, attended with so surprising a result, has been based, and even the method upon which it has been conducted; so as to strip the proceeding of much of that incomprehensible character, which, in the view of the great mass of those who consider it, without being able to follow the steps of the actual investigation, is generally attached to it, and to show at least

Fig. 1.



the spirit of the reasoning by which the solution of the problem has been accomplished.

For this purpose, it will be necessary, first, to explain the nature and character of those disturbances which were observed and which could not be ascribed to the attraction of any of the known planets; and, secondly, to show in what manner an undiscovered planet, revolving outside the known limits of the solar system, could produce such effects.

5. At the epoch of this celebrated discovery, the solar system was supposed to consist of the principal planets, Mercury, Venus, the Earth, Mars, Jupiter, Saturn, and Uranus, revolving round the sun, in the order in which we have given their names, and at distances bearing to each other the proportion which is represented with tolerable exactness in fig. 1. Between Mars and Jupiter a group of very minute bodies, called planetoids or asteroids, had been discovered, occupying the place of a planet, which had been supposed to be wanting in the system. Since the discovery which now engages us, the number of these planetoids discovered has been greatly increased, its amount being at the time we write (1st February, 1855,) not less than 33.

If the reader will carry in his eye the plan of the solar system thus exhibited, he will find the following observations and reasoning not difficult to comprehend.

6. The planet Uranus, revolving at the extreme limits of the solar system, was the object in which were observed those disturbances which, not being the effects of the action of any of the known planets, raised the question of the possible existence of another planet exterior to it, which might produce them.

After the discovery of that planet by Sir W. Herschel, in 1781, its motions, being regularly observed, supplied the data by which its elliptic orbit was calculated, and the disturbances produced upon it by the masses of Jupiter and Saturn ascertained, the other planets of the system, by reason of their remoteness, and the comparative minuteness of their masses, not producing any sensible effects. Tables founded on these results were computed, and ephemerides constructed, in which the places at which the planet ought to be found from day to day for the future were duly registered.

The same kind of calculations which enabled the astronomer thus to predict the future places of the planet, would, as is evident, equally enable him to ascertain the places which had been occupied by the planet in times past. By thus examining, retrospectively, the apparent course of the planet over the firmament, and comparing its computed places at particular epochs with those of stars which had been observed, and which had subsequently disappeared, it was ascertained that several of these stars had in fact been Uranus itself, whose planetary character had not been recognised from its appearance, owing to the imperfection of the telescopes then in use; nor from its apparent motion, owing to the observations not having been sufficiently continuous and multiplied.

In this way it was ascertained, that Uranus had been observed, and its position recorded as a fixed star, six times by Flamstead: viz., once in 1690, once in 1712, and four times in 1715;—once by Bradley in 1753, once by Mayer in 1756, and twelve times by Lemonnier between 1750 and 1771.

Now, although the observed positions of these objects, combined with their subsequent disappearance, left no doubt whatever of their identity with the planet, their observed places deviated sensibly from the places which the planet ought to have had, according to the computations founded upon its motions after its discovery in 1781. If these deviations could have been shown to be irregular and governed by no law, they would be ascribed to errors of observation. If, on the other hand, they were found to follow a regular course of increase and decrease in determinate directions, they would be ascribed to the agency of some undiscovered disturbing cause, whose action at the epochs of the ancient observations was different from its action at more recent periods.

The ancient observations were, however, too limited in number and too discontinuous to demonstrate in a satisfactory manner the irregularity or the regularity of the deviation. Nevertheless, the circumstance raised much doubt and misgiving in the mind of Bouvard, by whom the tables of Uranus, based upon the modern observations, were constructed; and he stated that he would leave to futurity the decision of the question, whether these deviations were due to errors of observation, or to *an undiscovered disturbing agent*. We shall presently be enabled to appreciate the sagacity of this reserve.

7. The motions of the planet continued to be assiduously observed, and were found to be in accordance with the tables for about fourteen years from the date of the discovery of the planet. About the year 1795, a slight discordance between the tabular and observed places began to be manifested, the latter being a little in advance of the former, so that the observed longitude L of the planet was greater than the tabular longitude L′. After this, from year to year, the advance of the observed upon the tabular place increased, so that the excess L—L′ of the observed above the tabular longitude was continually augmented. This increase of L—L′ continued until 1822, when it became stationary, and afterwards began to decrease. This decrease continued until about 1830-31, when the deviation L—L′ disappeared, and the tabular and observed longitudes again agreed. This accordance, however, did not long prevail. The planet soon began to fall behind its tabular place, so that its observed longitude L, which before 1831 was greater than the tabular longitude L′, was now less; and the distance L′—L of the observed behind the tabular place increased from year to year, and still increases.

It appears, therefore, that in the deviations of the planet from its computed place, there was nothing irregular and nothing compatible with the supposition of any cause depending on the accidental errors of observation. The deviation, on the contrary, increased gradually in a certain direction to a certain point; and having attained a maximum, then began to decrease, which decrease still continues.

The phenomena must, therefore, be ascribed to the regular agency of some undiscovered disturbing cause.

8. It is not difficult to demonstrate that deviations from its computed place, such as those described above, would be produced by a planet revolving in an orbit having the same or nearly the same plane as that of Uranus, which would be in heliocentric conjunction with that planet at the epoch at which its advance beyond its computed place attained its maximum.

Let A B C D E F, fig. 2, represent the arc of the orbit of Uranus described by the planet during the manifestation of the perturbations. Let N N′ represent the orbit of the supposed undiscovered planet in the same plane with the orbit of Uranus. Let *a*, *b*, *c*, *d*, *e*, and *f* be the positions of the latter when Uranus is at the points A, B, C, D, E, and F. It is therefore supposed, that Uranus when at D is in heliocentric conjunction with the supposed planet, the latter being then at *d*.

The directions of the orbital motions of the two planets are indicated by the arrows beside their paths; and the directions of the disturbing forces * exercised by the supposed planet on Uranus are indicated by the arrows beside the lines joining that planet with Uranus.

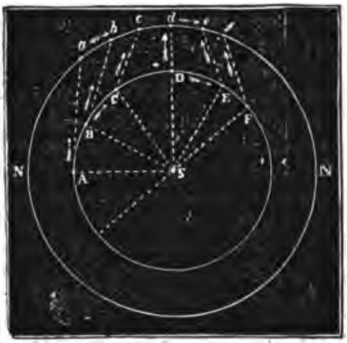


Fig. 2.

Now, it will be quite evident, that the attraction exerted by the supposed planet at *a* on Uranus at A tends to accelerate the latter. In like manner, the forces exerted by the supposed planet at *b* and *c* upon Uranus at B and C tend to accelerate it. But as Uranus approaches to D, the direction of the disturbing force, being less and less inclined to that of the orbital motion, has a less and less accelerating influence, and on arriving at D, the disturbing force being in the direction D *d* at right angles to the orbital motion, all accelerating influence ceases.

After passing D the disturbing force is inclined *against* the motion, and instead of accelerating retards it; and as Uranus takes successively the positions E, F, &c., it is more and more inclined, and its retarding influence more and more increased, as will be evident if the directions of the retarding force and the orbital motion, as indicated by the arrows, be observed.

---

* To simplify the explanation, the effect of the attraction of Uranus on the sun is omitted in this illustration. In the chapter on Perturbations in my "Handbook on Astronomy," the method of determining the exact direction of the disturbing force is explained.

It is then apparent, that from A to D the disturbing force, accelerating the orbital motion, will transfer Uranus to a position in advance of that which it would otherwise have occupied; and after passing D, the disturbing force retarding the planet's motion will continually reduce this advance, until it bring back the planet to the place it would have occupied had no disturbing force acted; after which, the retardation being still continued, the planet will fall behind the place it would have had if no disturbing force had acted upon it.

Now it is evident that these are precisely the *kind* of disturbing forces which act upon Uranus; and it may, therefore, be inferred that the deviations of that planet from its computed place are the physical indications of the presence of a planet exterior to it, moving in an orbit whose plane either coincides with that of its own orbit, or is inclined to it at a very small angle, and whose mass and distance are such as to give to its attraction the degree of intensity necessary to produce the alternate acceleration and retardation which have been observed.

Since, however, the intensity of the disturbing force depends conjointly on the quantity of the disturbing mass and its distance, it is easy to perceive that the same disturbance may arise from different masses, provided that their distances are so varied as to compensate for their different weights or quantities of matter. A double mass at a fourfold distance will exert precisely the same attraction. The question, therefore, under this point of view, belongs to the class of indeterminate problems, and admits of an infinite number of solutions. In other words, an unlimited variety of different planets may be assigned, exterior to the system which would cause disturbances observed in the motion of Uranus, so nearly similar to those observed, as to be distinguishable from them only by observations more extended and elaborate than any to which that planet could possibly have been submitted since its discovery.

9. The idea of taking these departures of the observed from the computed place of Uranus, as the data for the solution of the problem to ascertain the position and motion of the planet which could cause such deviations, occurred, nearly at the same time, to two astronomers, neither of whom at that time had attained either the age or the scientific standing which would have raised the expectations of achieving the most astonishing discovery of modern times.

M. Le Verrier, in Paris, and Mr. J. C. Adams, Fellow and Assistant Tutor of St. John's College, Cambridge, engaged in the investigation, each without the knowledge of what the other was doing, and believing that he stood alone in his adventurous and, as would then have appeared, hopeless attempt. Nevertheless, both not only solved the problem, but did so with a completeness that filled the world with astonishment and admiration, in which none more ardently shared than those who, from their own attainments, were best qualified to appreciate the difficulties of the question.

The question, as has been observed, belonged to the class of indeterminate problems. An infinite number of different planets might be assigned which would be equally capable of producing the observed disturbances. The solution, therefore, might be theoretically correct, but practically unsuccessful. To strip the question as far as possible of this character, certain conditions were assumed, the existence of which might be regarded as in the highest degree probable. Thus it was assumed that the disturbing planet's orbit was in or nearly in the plane of that of Uranus, and therefore in that of the ecliptic; that its motion in this orbit was in the same direction as that of all the other planets of the system, that is, according to the order of the signs; that the orbit was an ellipse of very small eccentricity; and, in fine, that its mean distance from the sun was, in accordance with the general progression of distances noticed by Bode, nearly double the mean distance of Uranus. This last condition, combined with the harmonic law, gave the inquirer the advantage of the knowledge of the period, and therefore of the mean heliocentric motion.

Assuming all these conditions as provisional data, the problem was reduced to the determination, at least as a first approximation, of the mass of the planet and its place in its orbit at a given epoch, such as would be capable of producing the observed alternate acceleration and retardation of Uranus.

The determination of the heliocentric* place of the planet at a given epoch would have been materially facilitated if the exact time at which the amount of the advance (L—L′) of the observed upon the tabular place of the planet had attained its maximum were known; but this, unfortunately, did not admit of being ascertained with the necessary precision. When a varying quantity attains its maximum state, and, after increasing, begins to diminish, it is stationary for a short interval; and it is always a matter of difficulty, and often of much uncertainty, to determine the exact moment at which the increase ceases and the decrease commences. Although, therefore, the heliocentric place of the disturbing planet could be nearly assigned about 1822, it could not be determined with the desired precision.

---

* That is, the place in which the planet would appear to be, if the observer were at the centre of the system, where the sun is.

Assuming, however, as nearly as was practicable, the longitude of Uranus at the moment of heliocentric conjunction* with the disturbing planet, this, combined with the mean motion of the sought planet, inferred from its period, would give a rough approximation to its place for any given time.

10. Rough approximations were not, however, what MM. Le Verrier and Adams sought. They aimed at more exact results; and, after investigations involving all the resources and exhausting all the vast powers of analysis, these eminent geometers arrived at the following elements of the undiscovered planet:—

	Le Verrier.	Adams.
Epoch of the elements	1 Jan. 1847.	1 Jan. 1846.
Mean longitude at the epoch . .	318° 47′·4	323° 2′
Mean distance of planet from sun .	36·1539	37·2474
Eccentricity of the orbit . . .	0·107610	0·120615
Longitude of perihelion . . .	284° 45′·8	299° 11′
Mass (sun = 1)	0·00010727	0·00015003

11. On the 23rd September, 1846, Dr. Galle, one of the astronomers of the Royal Observatory at Berlin, received a letter from M. Le Verrier, announcing to him the principal results of his calculations, informing him that the longitude of the sought planet must then be 326°, and requesting him to look for it. Dr. Galle, assisted by Professor Enché, accordingly did "look for it," and found it that very night. It appeared as a star of the 8th magnitude, having the longitude of 326° 52′, and consequently only 52′ from the place assigned by M. Le Verrier. The calculations of Mr. Adams, reduced to the same date, gave for its place 329° 19′, being 2° 27′ from the place where it was actually found.

To illustrate the relative proximity of these remarkable predictions to the actual observed place, let the arc of the ecliptic, from long. 323° to long. 330°, be represented in fig. 3. The place assigned by M. Le Verrier for the sought planet is indicated by the small circle at L, that assigned by Mr. Adams by the small circle at A, and the place at which it was actually found by the dot at N. The distances of L and A from N may be appreciated by the circle which is described around the dot N, and which represents the apparent disk of the moon.

---

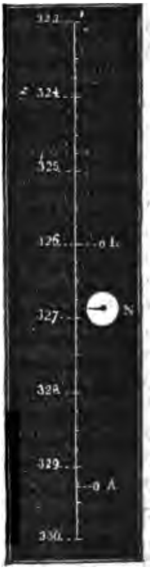
* Two objects are said to be in heliocentric conjunction, when they are so placed that they would be seen in the same direction by an observer looking at them from the sun.

The distance of the observed place of the planet from the place predicted by M. Le Verrier was less than two diameters, and from that predicted by Mr. Adams less than five diameters of the lunar disc.

12. In obtaining the elements given above, Mr. Adams based his calculations on the observations of Uranus made up to 1840, while the calculations of M. Le Verrier were founded on observations continued to 1845. On subsequently taking into computation the five years ending 1845, Mr. Adams concluded that the mean distance of the sought planet would be more exactly taken at 33·33.

After the planet had been actually discovered, and observations of sufficient continuance were made upon it, the following proved to be its more exact elements:—

Fig. 3.



	Greenwich.
Epoch of the elements	1 Jan. 1847, M. Noon.
Mean longitude at the epoch . . .	328° 32′ 44″·2.
Mean distance from sun . . .	30·0367.
Eccentricity of orbit	0·00871946.
Longitude of perihelion	47° 12′ 6″·50.
Longitude of ascending node . . .	130° 4′ 20″·81.
Inclination of orbit	1° 46′ 58″·97.
Periodic time	164·6181 years.
Mean annual motion	2°·18688.

13. Now it will not fail to strike every one who devotes the least attention to this interesting question, that considerable discrepancies exist, not only between the elements presented in the two proposed solutions of this problem, but between the actual elements of the discovered planet and both of these solutions.

There were not wanting some who, viewing these discordances, did not hesitate to declare that the discovery of the planet was the result of chance, and not, as was claimed, of mathematical reasoning, since, in fact, the planet discovered was not identical with either of the two planets predicted.

To draw such a conclusion from such premises, however, betrays a total misapprehension of the nature and conditions of the problem. If the problem had been determinate, and, consequently, one which admits of but one solution, then it must have been inferred, either that some error had been committed in the calculations which caused the discordance between the observed and computed elements, or that the discovered planet was not that which was sought, and which was the physical cause of the observed disturbances of Uranus. But the problem, as has been already explained, being more or less indeterminate, admits of more than one,—nay, of an indefinite number of different solutions, so that many different planets might be assigned which would equally produce the disturbances which had been observed; and this being so, the discordance between the two sets of predicted elements, and between both of them and the actual elements, are nothing more than might have been anticipated, and which, except by a chance, against which the probabilities were millions to one, were, in fact, inevitable.

So far as depended on reasoning, the prediction was verified; so far as depended on chance it failed. Two planets were assigned, both of which lay within the limits which fulfilled the conditions of the problem. Both, however, differed from the true planet in particulars which did not affect the conditions of the problem. All three were circumscribed within those limits, and subject to such conditions as would make them produce those deviations or disturbances which were observed in the motions of Uranus, and which formed the immediate subject of the problem.

14. It may be satisfactory to render this still more clear, by exhibiting in immediate juxtaposition the motions of the hypothetical planets of MM. Le Verrier and Adams and the planet actually discovered, so as to make it apparent that any one of the three, under the supposed conditions, would produce the observed disturbances. We have accordingly attempted this in fig. 4, where the orbits of Uranus, of Neptune, and of the planets assigned by MM. Le Verrier and Adams are laid down, with the positions of the planets respectively in them for every fifth year, from 1800 to 1845 inclusively. This plan is, of course, only roughly made; but it is sufficiently exact for the purposes of the present illustration. The places of Uranus are marked by O,

those of Neptune by ⊙, those of M. Le Verrier's planet by ⊖, and those of Mr. Adams' planet by ⊕.

It will be observed that the distances of the two planets assigned by MM. Le Verrier and Adams, as laid down in the diagram, differ less from the distance of the planet Neptune than the mean distances given in their elements differ from the mean distance of Neptune. This is explained by the eccentricities of the orbit, which, in the elements of both astronomers, are considerable, being nearly an eighth in one and a ninth in the other, and by the positions of the supposed planets in their respective orbits.

If the masses of the three planets were equal, it is clear that the attraction with which Le Verrier's planet would act upon Uranus, would be less than that of the true planet, and that of Adams' planet still more so, each being less in the same ratio as the square of its distance from Uranus is greater than that of Neptune. But if the planets are so adjusted that what is lost by distance is gained by the greater masses, this will be equalised, and the supposed planet will exert the same disturbing force as the actual planet, so far as relates to the effects of variation of distance. It is true that, throughout the arcs of the orbits over which the observations extend, the distances of the three planets in simultaneous positions are not everywhere in exactly the same ratio, while their masses must necessarily be so; and, therefore, the relative masses, which would produce perfect compensation in one position, would not do so in others. This cause of discrepancy would operate, however, under the actual conditions of the problem, in a degree altogether inconsiderable, if not insensible.

But another cause of difference in the disturbing action of the real and supposed planets would arise from the fact, that the directions of the disturbing forces of all the three planets are different, as will be apparent on inspecting the figure in which the degree of divergence of these forces at each position of the planets is indicated; but it will be also apparent, that this divergence is so very inconsiderable that its effect must be quite insensible in all positions in which Uranus can be seriously affected. Thus, from 1800 to 1815, the divergence is very small. It increases from 1815 to 1835; but it is precisely here, near the epoch of heliocentric conjunction, which took place in 1822, that all the three planets cease to have any direct effect in accelerating the motion of Uranus. When the latter planet passes this point sufficiently to be sensibly retarded by the disturbing action, as is the case after 1835, the divergence again becomes inconsiderable.

From these considerations it will therefore be understood, that the disturbances of the motion of Uranus, so far as these were ascertained by observation, would be produced without sensible difference, either by the actual planet which has been discovered, or by either of the planets assigned by MM. Le Verrier and Adams, or even by an indefinite number of others which might be assigned, either within the path of Neptune, or between it and that of Adams' planet, or, in fine, beyond the latter—within certain assignable limits.

15. That the planets assigned by MM. Le Verrier and Adams are not identical with the planet to the discovery of which their researches have conducted practical observers is, therefore, true; but it is also true that, if they or either of them had been identical with it, such excessive amount of agreement would have been purely accidental, and not at all the result of the sagacity of the mathematician. All that human sagacity could do with the data presented by observation was done. Among an indefinite number of *possible* planets capable of producing the disturbing action, two were assigned, both of which were, for all the purposes of the inquiry, so nearly coincident with the real planet as inevitably and immediately to lead to its discovery.

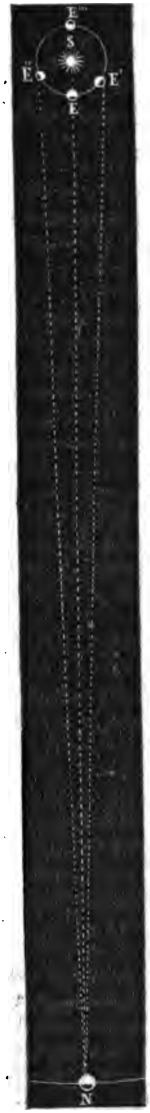
16. It might appear from considering merely the enormous distance of this planet from the earth, that the problem to ascertain the rate of its motion, and the time it takes to make a complete revolution round the sun, would be attended with great difficulty; nothing, on the contrary, can be more easy or simple. By observing the place of the planet with precision on any given night,—say, for example, on the 1st January, 1853,—and again on the 1st January, 1854, it will be found to have moved through 2·187°; we infer, therefore, that this is the rate of its annual motion; and this inference would be verified by repeating the same observation on the 1st of January, 1855, and, in a word, on the same night in each succeeding year.

Having thus ascertained that Neptune moves round the sun at the rate of 2·187° per annum, the question is: how long he will take to make a complete revolution—that is 360°—round the sun; and this, it is clear, is a question in the simple Rule of Three, that can be solved by any school-boy, and is thus stated—

$$2{\cdot}187^\circ : 360^\circ :: 1 \text{ year} : \frac{360}{2{\cdot}187} = 164{\cdot}6 \text{ years.}$$

Thus it appears that this planet will make a complete revolution round the sun in about 164 years and 7 months, and although not more than a few years have elapsed since the date of its discovery, we are just as certain, that it will complete its revolution in that interval as our posterity will be, who will witness the completion of its period, in the year of our Lord 2011.

Fig. 5.



17. There is a remarkable astronomical law which was discovered, as a matter of fact, by Kepler, and shown by Newton to be a necessary consequence of the principle of universal gravitation, called the harmonic law; according to this celebrated law, the successive distances of the planets from the sun, have a certain fixed relation to their times of revolutions, shortly called their periodic times, by means of which their relative distances can be easily computed, when their periodic times are known. This celebrated law is expressed as follows:—

The squares of the numbers which express the periodic times of any two planets, are in the same proportion as the cubes of the numbers which express their distances from the sun.

This rule reduces the problem to determine the distance of Neptune from the sun to a question in the simple Rule of Three.

The periodic time of the earth being a year, will be expressed by 1, and that of Neptune will be, as already shown, 164·6; now the squares of these numbers are 1 and 27093. To find the cube of Neptune's distance, is therefore a Rule of Three question stated as follow:—

1 : 27093 : : 1 : 27093.

Therefore this number 27093 is in fact the cube of Neptune's distance from the sun, the earth's distance from the sun being expressed by 1. To find Neptune's distance, therefore, we have only to find the number whose cube is 27093, and by the ordinary processes of arithmetic, that number is found to be 30·034.

We may, therefore, state in round numbers, that Neptune is 30 times farther from the sun than the earth. But the distance of the earth from the sun being, in round numbers, 100 millions of miles; it follows that the distance of Neptune from the sun is, in round numbers, about 3000 millions of miles. Greater numerical precision than this has been attained by the computations of astronomers, but the purpose of our numerous readers will be best served at present by adhering to these round numbers.

18. To convey some notion of the prodigious

scale upon which the orbital motion of this planet takes place, we have represented in fig. 5, the orbit of the earth, E, E′, E″, E‴, the distance of E from S, the sun, being 100 millions of miles; S N will then be upon the same scale, the distance of Neptune from the sun.

Although it is easy by this expedient to convey a sufficiently exact notion of the relative distances of these planets from the sun, it is by no means so easy to acquire any adequate idea of their actual distances, or what is the same, of the scale of the solar system.

To obtain, even in the case of magnitudes infinitely less than these, any just notions, it is necessary to compare them, and, as it were, to measure them by some standard of magnitude, with which we have a practical familiarity. Let us see then, whether by such an expedient we can obtain some notion, however faint, of the scale of the solar system, at the extreme limit of which Neptune moves.

19. Every one is at this time familiar enough, with the motion of a railway train having a given speed, say, for example, 30 miles an hour; we know that in such a train, moving with that speed, stoppages included, we can go from London to Liverpool in 7 hours; in what time, let us ask, could we be transported in such a train from the sun to the earth? The distance, as already stated, is 100 millions of miles; if this be divided by 30 we shall find the number of hours which such a journey would take, this number would therefore be 3,333333 hours. If this be divided successively by 24 and by 365¼ we shall find the number of days and of years in such a journey; the result of such a calculation in round numbers will show that such a train will take 380 years to move from the sun to the earth.

But Neptune being, as we have seen, 30 times more distant than the earth from the sun, it would take the same train an interval 30 times longer to move to that planet; we therefore arrive at the astounding conclusion that a railway-train moving constantly without stoppage would take 114000 years to move from the sun to Neptune, that is to the extreme limit of the solar system.

The circumference of a circle, whose diameter is 6000, is 18849; now since the diameter of Neptune's orbit is 6000 millions of miles, its circumference is 18849 millions of miles, and round this circumference the planet moves in 164·6 years, and it therefore moves at the rate of 114,500000 miles per year, or 313500 miles per day, or 13000 miles an hour.

Such is the colossal scale on which the movements of the system are conducted.

20. It will doubtless be asked, whether the magnitude of this

body have any proportion to such prodigious distances and motions? or whether, indeed, its magnitude at such a distance as 3000 millions of miles, can be at all ascertained? Difficult, nevertheless, as such a problem may seem, it is, on the contrary, among the most easy and simple which are presented to the astronomer.

When a powerful astronomical telescope is directed to a planet, the object which to the naked eye appears as a mere stellar point of light, is seen with a circular disc like that of the moon, but in general much smaller. The visual angle of the moon's disc is 1800″; now it is found that the visual angle of the disc of Neptune is only 2·8″, and, therefore, is very nearly 643 times less than the disc of the moon; but the distance of Neptune is 30 times greater than that of the sun, and the distance of the sun is 400 times greater than that of the moon. Therefore the distance of Neptune is 12000 times greater than that of the moon, consequently it will follow, that if the moon were removed to Neptune's distance, its visual angle would be 12000 times less than it is; but from what has been just stated it appears that the visual angle of Neptune is only 643 times less than that of the moon. It follows, therefore, that the actual diameter of Neptune must be greater than the actual diameter of the moon, in the proportion of 12000 to 643, or 19 to 1 very nearly. But since we know the diameter of the moon to be a little more than 2000 miles, it follows that the actual diameter of Neptune will be about 38000 miles.

This is a rough method of calculation which we have adopted to render the point familiar to those who are not accustomed to the more exact methods of astronomical calculations.

How little the result nevertheless varies from the truth, will be perceived when we state, that, according to the most exact observations and calculations of astronomers, the actual diameter of Neptune is 37500 miles.

21. A satellite of this planet was discovered by Mr. Lassell in October, 1846, and was afterwards observed by other astronomers both in Europe and the United States. The first observations then made raised some suspicions as to the presence of another satellite as well as of a ring analogous to that of Saturn. Notwithstanding the numerous observers, and the powerful instruments which have been directed to the planet since the date of these observations, nothing has been detected which has had any tendency to confirm these suspicions.

The existence of the satellite first seen by Mr. Lassell has, however, not only been fully established, but its motion, and the elements of its orbit, have been ascertained, first by the observations of M. O. Struve in September and December, 1847, and later, and more fully, by those of his late relative M. Auguste Struve, in 1848-9.

From these observations it appears, that the distance of the satellite from the planet at its greatest elongation subtends an angle of 18" at the sun; and since the diameter of the planet subtends an angle of 2"·8 at the same distance, it follows, therefore, that the distance of the satellite from the centre of the planet is equal to thirteen semidiameters of the latter.

The mean daily angular motion of the satellite round the centre of the planet is, according to the observations of Struve, 61°·2625, and, consequently, the period of the satellite is—

$$\frac{360}{61{\cdot}2625} = 5{\cdot}8763 \text{ days},$$

or $5^d\ 21^h\ 1{\cdot}8^m$, a result which is subject to an error not exceeding 5 minutes.

If the semidiameter of the planet be 18750 miles, the actual distance of the satellite is

$$18750 \times 12 = 225000 \text{ miles},$$

being a little less than the distance of the moon from the earth's centre.

22. If it excite surprise that the dimensions of a globe so enormously distant from the earth as that of Neptune should be so exactly and so easily measured, it will not create less astonishment when we affirm that the mass of matter in that globe can be, and has been weighed, and not only weighed, but weighed with as much or even more precision than that which is attained by the chemist in the operations conducted upon the small masses of matter under his hands.

What then, it will naturally enough be asked, can be the form and structure of the balance, by which an operation so wonderful can be performed?

Let us see whether we cannot explain this.

If a mass of matter attached to the extremity of a string, the other extremity of which is attached to a fixed point, be whirled round in a circle, of which that fixed point is the centre, the string will be, as every one knows, stretched with a certain force, and that this force will be greater and greater as the velocity with which the body is whirled is increased. Now the moon whirls round the earth with just such a circular motion, and if it were connected by a string with the centre of the earth, that string would be stretched with a force depending upon the velocity of the moon's motion; but since no such string exists, something else must exist which will exercise the same force upon the moon as the string would, and that something is the earth's attraction.

It is proved by theory, and verified by experiment, that the force with which the string connecting such a body with the centre would be stretched, would increase in the same proportion as the square of the velocity of the revolving body increases, other things being the same. If, therefore, the moon's velocity in whirling round the earth were twice what it is, the force with which it would react against the earth's attraction, would be four times greater than it is, and as the earth's attraction would still be the same, the moon, in that case, would escape from her orbit, and would depart to a greater distance from the earth. If, on the other hand, the moon moved with half its present velocity, the force with which it would stretch the string would be four times less than it is, and being then less than the earth's attraction upon it, the moon would fall towards the earth to a much less distance. But since the moon neither departs to greater distances nor approaches to less distances, it follows that the attraction of the earth upon it is neither more nor less than that with which a string would be stretched which would connect the moon with the centre of the earth.

Now we have seen by what has been explained, that Neptune, as well as the earth, has a moon, and moreover, that this moon whirls round Neptune at a distance a little less than that at which our moon moves round the earth. To simplify the question, let us suppose for a moment that these distances are equal. If then Neptune's moon had the same velocity as ours, a string connecting it with Neptune would be stretched with the same force as that with which a string would be stretched connecting the moon with the earth; and since the attraction of the two planets on their respective moons is represented by the tension of such string, it would follow, in that case, that the two planets would exert equal attractions on moons revolving at equal distances from them. But since these attractions depend only on the quantities of matter in the two planets, or what is the same on their weights, it would, in that case, follow, that the weight of Neptune would be equal to that of the earth.

But Neptune's moon, instead of revolving in the same time as ours, revolves as it appears, by what has been explained, in 5·8763 days. Now we have just explained that the force with which the whirling body would stretch a string increases, other things being the same, in the proportion of the square of its velocity, and since our moon takes 27·322 days to make a complete revolution, while that of Neptune makes a revolution in 5·876 days, the velocity of the latter will be greater than that of the former in the proportion of 5876 to 27322; and consequently the forces with which they will react upon the planetary attractions which hold them in their orbits will be proportional to the squares of these numbers. But the squares of these numbers, if computed, will be found to be in the proportion of $21\frac{2}{3}$ to 1 very nearly. It would follow, therefore, that the weight of Neptune is $21\frac{2}{3}$ times that of the earth.

But it must not be forgotten that in this calculation we have supposed that the distance of the satellite from Neptune is equal to the distance of the moon from the earth, but in fact the distance of Neptune's satellite is less than that of the moon, in the proportion of 225 to 238, and, therefore, the estimate of the mass of Neptune, computed as above, upon the supposition of the exact equality of the two distances, must be reduced in the same proportion, which would make Neptune's mass 20 times that of the earth.

This, as in the former case, is a very rough method of calculation, adopted to render familiar a problem, which, in its more exact details, would be much too difficult for any but professed astronomers perfectly to understand. By more exact methods it appears that the weight of Neptune is about 19 times that of the earth.

23. The relative bulks, or volumes, of globes being in the proportion of the cubes of their diameters, and the diameter of Neptune being 37500 miles, while that of the earth is about 7900 miles, it follows that the bulk of Neptune is about 107 times greater than that of the earth; or that 107 globes like the earth, being rolled into one, would form a planet equal to Neptune.

24. Since the brightness of the sun's light, and the warmth produced by its heat, decrease in the same proportion as the superficial magnitude of his disc decreases, and since the diameter of that disc decreases in the same proportion as the distance of the observer from the sun increases, it follows that the superficial magnitude of the sun's disc, and therefore the brightness of the light of day, and the warmth of the solar rays, will be less at Neptune than they are at the earth, in the same proportion in which the square of Neptune's distance from the sun is greater than the square of the earth's distance; and since Neptune is 30 times more distant than the earth, it follows that the brightness of day and the sun's warmth at Neptune are 900 times less than at the earth.

25. The apparent diameter of the sun, as seen from Neptune, being 30 times less than from the earth, is,

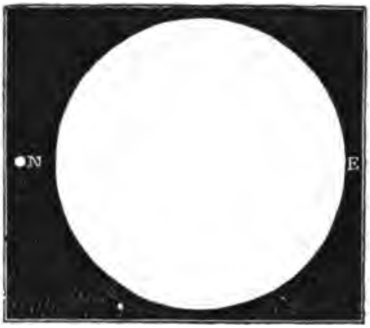
$$\frac{1800''}{30} = 60''.$$

The sun, therefore, appears of the same magnitude as Venus seen as a morning or evening star.

The relative apparent magnitudes are exhibited in fig. 6, at E and N.

It would, however, be a great mistake to infer that the light of the sun at Neptune approaches in any degree to the faintness of that of Venus at the earth. If Venus, when that planet appears as a morning or evening star, with the apparent diameter of 60", had a full disc (instead of one halved or nearly so, like the moon at the quarters), and if the actual intensity of light on its surface were equal to that on the surface of the sun, the light of the planet would be exactly that of the sun at Neptune. But the intensity of the light which falls on Venus is less than the intensity of the light on the sun's surface in the ratio of the square of Venus' distance to that of the sun's semidiameter, upon the supposition that the light is propagated according to the same law as if it issued from the sun's centre; that is, as the square of 37 millions to the square of half a million nearly, or as $37^2 : \frac{1}{4}$, that is, as 5476 to 1. If, therefore, the surface of Venus reflected (which it does not) all the light incident upon it, its apparent light at the earth (considering that little more than half its illuminated surface is seen) is about 11000 times less than the light of the sun at Neptune.

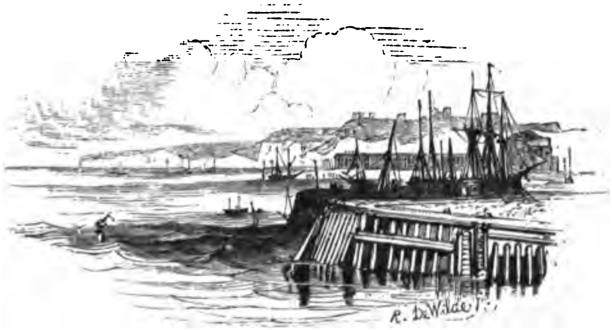
Fig. 6.



Small, therefore, as is the apparent magnitude of the sun at Neptune, the intensity of its daylight is probably not less than that which would be produced by about 20000 stars shining at once in the firmament, each being equal in splendour to Venus when that planet is brightest.

In addition to these considerations, it must not be forgotten that all such estimates of the comparative efficiency of the illuminating and heating power of the sun are based upon the supposition that his light is received under like physical conditions; and that many conceivable modifications in the physical state of the body or medium on or into which the light falls, and in the structure of the visual organs which it affects, may render light of an extremely feeble intensity as efficient as much stronger light is found to be under other conditions.

26. Messrs. Lassell and Challis have at times imagined that indications of some such appendage as a ring, seen nearly edgewise, were perceptible upon the disc of Neptune. These conjectures have not yet received any confirmation. When the declination of the planet shall have so far increased as to present the ring, if such an appendage be really attached to the planet, at a less oblique angle to the visual ray, the question will probably be decided.



THE TIDES.

1. Their correspondence with the lunar phases known at an early period.—2. Erroneous notions prevalent as to their causes.—3. Not caused by the moon's attraction.—4. But by the inequality of its attraction.—5. Calculation of this inequality.—6. Solar tides.—7. Difference between the power of the sun and moon to produce a tide.—8. Spring and neap tides.—9. Why the tides are not directly under the moon.—10. Establishment of the port.—11. Effects of the form of the coasts upon the local tides.—12. Dr. Whewell's analysis of the progress of the tidal wave.—13. Age of the tide.—14. Velocity of the tide.—15. Undulations.—16. Motion of the crest of a wave.—17. Range of the tide.—18. How affected by the weather.

1. The phenomena of the tides of the ocean are too remarkable and too important to the social and commercial interests of mankind, not to have attracted notice at an early period in the progress of knowledge. The intervals between the epochs of high and low water everywhere corresponding with the intervals between the passage of the moon over the meridian above and below the horizon, suggested naturally some physical connexion between these two phenomena, and indicated the probability of the cause of the tides being found in the motion of the moon.

Kepler developed this idea, and demonstrated the close connexion of the phenomena; but it was not until the theory of

GRAVITATION was established by Newton, and its laws fully developed, that all the circumstances of the tides were clearly explained, and shown incontestably to depend on the influence of the sun and moon.

2. There are few subjects in physical science about which there prevail more erroneous notions among those who are but a little informed, than with respect to the tides. A common idea is, that the attraction of the moon draws the waters of the earth toward that side of the globe on which it happens to be placed, and that consequently they are heaped up on that side, so that the oceans and seas acquire there a greater depth than elsewhere; and thus it is attempted to be established that high water will take place under, or nearly under, the moon. But this neither corresponds with the fact, nor, if it did, would it explain it. High water is not produced merely under the moon, but is equally produced upon those parts most removed from the moon. Suppose a meridian of the earth so selected, that if its plane were continued beyond the earth, it would pass through the moon; then we find that, subject to certain modifications, a great tidal wave, or what is called *high water*, will be formed *on both sides* of this meridian; that is to say, on the side next the moon, and on the side remote from the moon. As the moon moves in her monthly course round the earth, these two great tidal waves follow her. They are, of course, separated from each other by half the circumference of the globe. As the globe revolves with its diurnal motion upon its axis, every part of its surface passes successively under these tidal waves; and at all such parts as pass under them, there is the phenomenon of high water. Hence it is that in all places there are two tides daily, having an interval of about twelve hours between them. Now if the common notion of the cause of the tides were well founded, there would be only one tide daily; viz., that which would take place when the moon is at or near the meridian.

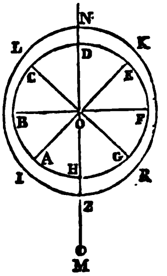
3. That the moon's attraction upon the earth simply considered would not explain the tides, is easily shown. Let us suppose that the whole mass of matter on the earth, including the waters which partially cover it, were attracted *equally* by the moon; they would then be equally drawn towards that body, and no reason would exist why they should be heaped up under the moon; for if they were drawn with the same force as that with which the solid globe of the earth under them is drawn, there would be no reason for supposing that the waters would have a greater tendency to collect towards the moon than the solid bottom of the ocean on which they rest. In short, the whole mass of the earth, solid and fluid, being drawn with the same

force, would equally tend towards the moon; and its parts, whether solid or fluid, would preserve among themselves the same relative position as if they were not attracted at all.

4. When we observe, however, in a mass composed of various particles of matter, that the relative arrangement of these particles is disturbed, some being driven in certain directions more than others, the inference is, that the component parts of such a mass must be placed under the operation of different forces; those which tend more than others in a certain direction being driven with a proportionally greater force. Such is, in fact, the case with the earth, placed under the attraction of the moon. Newton showed that the law of gravitation is such, that its attraction increases as the distance of the attracted object diminishes, and diminishes as the distance of the attracted object increases. The exact proportion of this change of energy of the attractive force, is technically expressed by stating that it is in the inverse proportion of the square of the distance; the meaning of which is, that the attraction which any body like the moon would exercise at any proposed distance, is four times that which it would exercise at twice the distance; nine times that which it would exert at three times the distance; one-fourth of that which it would exercise at half the distance, and one-ninth of that which it would exercise at one-third the distance, and so on. Thus we have an arithmetical rule, by which we can with certainty and precision say how the attraction of the moon will vary with any change of its distance from the attracted object. Let us see how this will be brought to bear upon the explanation of the effect of the moon's attraction upon the earth.

Let A, B, C, D, E, F, G, H, represent the globe of the earth, and, to simplify the explanation, let us first suppose the entire surface of the globe to be covered with water. Let M be the moon, and let H be the nearest, and D the most remote part of the earth. Now it will be very apparent that the various points of the earth's surface are at different distances from the moon: A and G are more remote than H; B and F still more remote; C and E more distant again, and D most remote of all. The attraction which the moon exercises at H is, therefore, greater than that which it exercises at A and G, and still greater than that which it produces at B and F; and the attraction which it exercises at D is least of all. Now this attraction equally affects matter in every state and condition. It affects the particles of fluid as well as solid matter,

Fig. 1.



but there is this difference between these effects; that where it acts upon solid matter, the component parts of which are at different distances from it, and therefore subject to different attractions, it will not disturb their relative arrangement, since such disturbances or disarrangements are prevented by the cohesion which characterises a solid body; but this is not the case with fluids, the particles of which are mobile, and which, when solicited by different forces, will have their relative arrangements disturbed in a corresponding manner.

The attraction which the moon exercises upon the shell of water which is collected immediately under it near the point H, is greater than that which it exercises upon the solid mass of the globe between H and D; consequently there will be a greater tendency of this attraction to draw the fluid which rests upon the surface at H towards the moon, than to draw the solid mass of the earth which is more distant.

As the fluid, by its nature, is free to obey this excess of attraction, it will necessarily heap itself up in a pile or wave over H, forming a more convex protuberance between R and I, as represented in the figure. Thus high water will take place at H, immediately under the moon. The water which thus collects at H, will necessarily flow from the regions B and F, where, therefore, there will be a diminished quantity of water in the same proportion.

But let us now consider what happens to that part of the earth, D, most remote from the moon. Here the waters being more remote from the moon than the solid mass of the earth under them, will be less attracted; and consequently will have a less tendency to gravitate towards the moon. The solid mass of the earth, D H, will, as it were, recede from the waters at N, in virtue of the excess of attraction, leaving these waters behind it, which will thus be heaped up at N, so as to form a convex protuberance between L and K, similar exactly to that which we have already described between R and I. As the difference between the attraction of the moon on the waters at Z and the solid earth under the waters, is nearly the same as the difference between its attraction on the latter and upon the waters at N, it follows that the height of the fluid protuberances at Z and N are nearly equal. In other words, the height of the tides on opposite sides of the earth, the one being under the moon and the other most remote from it, is nearly the same.

Now from this explanation it will be apparent, that the cause of the tides, so far as the action of the moon is concerned, is not, as is vulgarly supposed, due to the mere attraction of the moon; since, if that attraction were equal in all the component parts of the earth, there would assuredly be no tides. We are to look for the cause, then, not in the attraction of the moon, but in the *inequality* of its attraction on different parts of the earth. The greater this inequality is, the greater will be the tides. Hence, as the moon is subject to a slight variation of distance from the earth, it will follow, that when it is at its least distance, or at the point called *perigee*, the tides will be greatest; and when it is at the greatest distance, or at the point called *apogee*, the tides will be least; not because the entire attraction of the moon in the former case is greater than in the latter, but because the diameter of the globe bearing a greater proportion to the lesser distance than the greater, there will be a greater *inequality* of attraction.

It will doubtless occur to those who bestow on these observations a little reflection, that all which we have stated in reference to the effect produced by the attraction of the moon upon the earth, will also be applicable to the attraction of the sun. This is undoubtedly true; but in the case of the sun the effects are modified, in some very important respects, as will readily be seen. The sun is at four hundred times a greater distance than the moon, and the actual amount of its attraction on the earth would, on that account, be one hundred and sixty thousand times less than that of the moon; but the mass of the sun exceeds that of the moon in a much greater ratio than that of one hundred and sixty thousand to one. It therefore possesses a much greater attracting power in virtue of its mass, compared with the moon, than it loses by its increased distance. The consequence is, that it exercises upon the earth an attraction enormously greater than the moon exercises. Now, if the simple amount of its attraction were, as is commonly supposed, the cause of the tides, the sun ought to produce a vastly greater tide than the moon. The reverse is, however, the case, and the cause is easily explained. Let it be remembered, the tides are due solely to the *inequality* of the attraction on different sides of the earth, and the greater that inequality is, the greater will be the tides, and the less that inequality is, the less will be the tides.

5. The rate at which the attraction decreases with the increase of distance being clearly understood, nothing can be more easy of solution than the question of the difference between the influences of the sun and the moon in raising a tide.

The distance, M O, of the moon from the earth's centre is in round numbers sixty semi-diameters of the earth. Its distance, M H, from the nearest part of the earth's surface is therefore fifty-nine semi-diameters of the earth. Now since its attraction upon the entire solid mass of the earth is the same as if it were collected at the centre, O, and since we may regard its attraction on the waters to be the same as if they were collected at H, it will be evident that the moon's attraction on the solid earth will be less than its attraction upon the waters which lie on the nearer side of the earth in the proportion of the square of 60 to the square of 59, that is, as 3600 to 3481, and consequently the *difference* of the two attractions will be to the whole attraction exerted by the moon upon the earth as 119 to 3600, or what is the same, as 1 to 30½. Thus it appears that the moon's power to raise a tide on the nearer side of the earth is little less than a thirtieth part of its entire attraction on the earth.

By the same method of calculation, the power of the sun to raise a tide may be ascertained. The sun's distance from the centre of the earth is just twenty-four thousand semi-diameters of the earth, and its distance from the waters, on the nearer side of the earth is therefore twenty-three thousand nine hundred and ninety-nine semi-diameters. It follows, therefore, that its attraction on the waters on the nearer side exceeds the attraction on the earth, in the proportion of the square of 24000 to the square of 23999, that is, in the proportion of 576,000000 to 575,952001, and consequently the difference between its attraction on the waters, and its attraction on the solid earth, under the waters, has to its entire attraction the proportion of 47999 to 576,000000, or, what is the same, that of 1 to 12000; so that the sun's power to raise a tide is about the twelve-thousandth part of its whole attraction on the earth.

It appears, therefore, from this reasoning and calculation, that the moon's power to raise a tide is about the thirtieth part of its entire attraction, while the sun's power is the twelve-thousandth part of its attraction. If the entire attraction of the moon were equal to that of the sun, it would therefore follow very obviously that the moon's power to raise a tide would be greater than that of the sun, in the proportion of 12000 to 30, or what is the same, of 400 to 1. But the proportion in favour of the moon's influence is not nearly so great as this, because the entire attraction of the moon is much less than that of the sun. Let us consider in what proportion it is less. It is demonstrated by astronomers, that the mass of the sun is 28,394880 times greater than that of the moon. If the sun, therefore, were as near the earth as the moon is, its attraction would be 28,394880 times greater than that of the moon. But being at a distance 400 times greater than that of the moon, its attraction is diminished in the proportion of the square of 400, or 160000 to 1. Its actual attraction will, therefore, be found, relatively to that of the moon, by merely dividing 28,394880 by 160000, which gives 177½.

6. Since, therefore, the moon's power to raise a tide would be

400 times greater than that of the sun, if their entire attractions on the earth were equal, it will be less than this, in the ratio of 177½ to 1, inasmuch as the entire amount of the moon's attraction is less than that of the sun in that proportion. The moon's power to raise a tide is, therefore, greater than that of the sun in the ratio of 400 to 177½, or of 2¼ to 1. Other calculations make it about 2½ to 1.

7. It appears, therefore, that there is a solar as well as a lunar tide; and as the lunar tidal wave follows the diurnal motion of the moon, the solar tidal wave follows that of the sun. When the sun and moon are, therefore, either on the same or on opposite sides of the earth, which they are at the epochs of new and full moon, the two tidal waves will be superposed; but when their directions are most removed one from the other, which they are when the moon is in the quarters, the two tidal waves are most separated, being also ninety degrees of the earth's surface apart.

In the one case, a tide is produced corresponding to the sum of the effects of the actions of the moon and sun; and, in the other case, to their difference.

8. These circumstances will be better understood by referring to the illustrative diagrams. In fig. 2, S represents the sun, M the moon when new, and M′ when full. The solar and lunar tidal waves in these cases coincide, and are heaped one upon the other, producing what are called SPRING TIDES.

In fig. 3, S represents the sun, and M and M′ the moon in the quarters. In this case, the solar tidal wave is ninety degrees or a quarter of the earth's circumference from the lunar tidal wave, and the waters which form it are necessarily drawn from the side of the earth on which the lunar tide places itself. It is evident, therefore, that, in this case, the solar tide being formed at the expense of the lunar, the latter will be much less high. The tides in this case are called NEAP TIDES.

9. If physical effects followed immediately, without any appreciable interval of time, the operation of their causes, then the tidal wave produced by the moon would be on the meridian of the earth directly under and opposite to that luminary; and the same would be true of the solar tides. But the waters of the globe have, in common with all other matter, the property of inertia, and it takes a certain interval of time to impress upon them a certain change of position. Hence it follows that the tidal wave produced by the moon is not formed immediately under that body, but follows it at a certain distance. In consequence of this, the tide raised by the moon does not take place for two or three hours after the moon passes the meridian; and

as the action of the sun is still more feeble, there is a still greater interval between the transit of the sun and the occurrence of the solar tide.

But besides these circumstances, the tide is affected by other causes. It is not the separate effect of either of these bodies, but the combined effect of both, and at every period of the month, the time of actual high water is either accelerated or retarded by the sun. In the first and third quarters of the

Fig. 2.

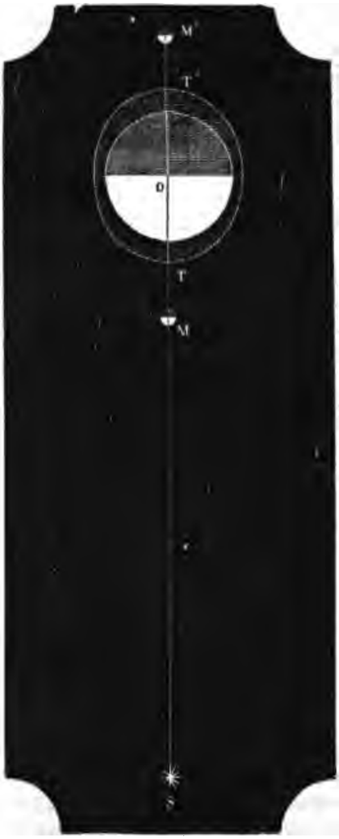
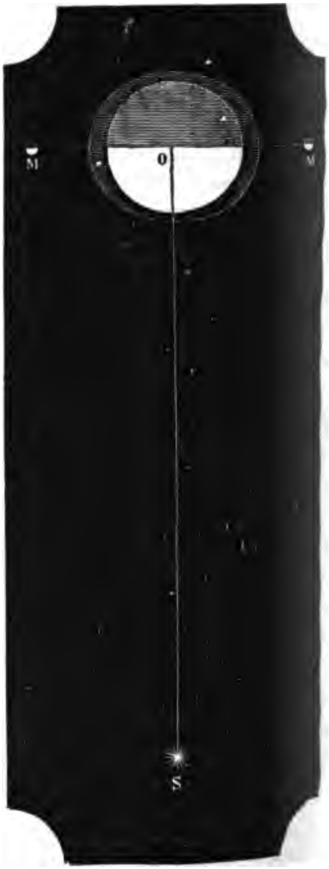


Fig. 3.



moon, the solar tide is westward of the lunar one; and, consequently, the actual high water, which is the result of the combination of the two waves, will be to the westward of the place where it would have been if the moon acted alone, and the time of high water will therefore be accelerated. In the second and fourth quarters the general effect of the sun is, for a similar reason, to produce a retardation in the time of high water. This effect, produced by the sun and moon combined, is what is commonly called the *priming* and *lagging* of the tides.

The highest spring tides occur when the moon passes the meridian about an hour after the sun; for then the maximum effect of the two bodies coincides.

The subject of the tides has received much attention from several scientific investigators in Europe. The discussions held at the annual meetings of the British Association for the Advancement of Science, on this subject, have led to the development of much useful information. The labours of Dr. Whewell have been especially valuable on these questions. Sir John Lubbock has also published a valuable treatise upon it. To trace the results of these investigations in all the details which would render them clear and intelligible, would greatly transcend the necessary limits of this notice. We shall, however, briefly advert to a few of the most remarkable points connected with these questions.

10. The apparent time of high water at any port in the afternoon of the day of new or full moon, is what is usually called the *establishment of the port*. Dr. Whewell calls this the vulgar establishment, and he calls the *corrected establishment* the mean of all the intervals of the tides and transits of half a month. This corrected establishment is consequently the luni-tidal interval corresponding to the day on which the moon passes the meridian at noon or midnight.

The two tides immediately following another, or the tides of the day and night, vary, both in height and time of high water, at any particular place with the distance of the sun and moon from the equator. As the vertex of the tide-wave always tends to place itself vertically under the luminary which produces it, it is evident that, of two consecutive tides, that which happens when the moon is nearest the zenith, or nadir, will be greater than the other; and, consequently, when the moon's declination is of the same denomination as the latitude of the place, the tide which corresponds to the upper transit will be greater than the opposite one, and *vice versâ*, the differences being greatest when the sun and moon are in opposition, and in opposite tropics. This is called the diurnal inequality, because its cycle is one day; but it varies greatly at different places, and its laws, which appear to be governed by local circumstances, are very imperfectly known.

11. We have now described the principal phenomena that would take place were the earth a sphere, and covered entirely with a fluid of uniform depth. But the actual phenomena of the tides are infinitely more complicated. From the interruption of the land, and the irregular form and depth of the ocean, combined with many other disturbing circumstances, among which are the inertia of the waters, the friction on the bottom and sides, the narrowness and length of the channels, the action of the wind, currents, difference of atmospheric pressure, &c. &c., great variation takes place in the mean times and heights of high water at places differently situated; and the inequalities above alluded to, as depending on the parallax of the moon, her position with respect to the sun, and the declination of the two bodies, are, in many cases, altogether obliterated by the effects of the disturbing influences, or can only be detected by the calculation and comparison of long series of observations.

12. According to Dr. Whewell, the general progress of the great tide-wave may be thus described:—It is only in the Southern ocean, between the latitudes of 30° and 70°, that a zone of water exists of sufficient extent to allow of the tide-wave being formed. Suppose, then, a line of contemporary tides, or *cotidal line*, to be formed in the Indian ocean, as the theory supposes, that is to say, in the direction of the meridian, and at a certain distance to the eastward of the meridian in which the moon is. As this tide-wave passes the Cape of Good Hope, it sends off a derivative undulation, which advances northward up the Atlantic ocean, preserving always a certain proportion of its original magnitude and velocity. In travelling along this ocean the wave assumes a curved form, the convex part keeping near the middle of the ocean, and ahead of the branches, which, owing to the shallower waters, lag behind on the American and African coasts, so that the cotidal lines have always a tendency to make very oblique angles with the shore, and, in fact, run parallel to it for great distances. The main tide, Dr. Whewell conceives, after reaching the Orkneys, will move forward in the sea bounded by the shores of Norway and Siberia on one side, and those of Greenland and America on the other, will pass the pole of the earth, and finally end its course on the shores in the neighbourhood of Behring's Straits. It may even propagate its influence through the straits, and modify the tides of the North Pacific. But a branch tide is sent off from this main tide into the German ocean; and this, entering between the Orkneys and the coast of

Norway, brings the tide to the east coast of England and to the coasts of Holland, Denmark, and Germany. Continuing its course, part of it passes through the strait of Dover and meets in the English channel the tide from the Atlantic, which arrives on the coast of Europe twelve hours later; but in passing along the English coast, another part of it is reflected from the projecting land of Norfolk upon the north coast of Germany, and again meets the tide-wave on the shores of Denmark. Owing to this interference of different tide-waves, the tides are almost entirely obliterated on the coast of Jutland, where their place is supplied by continual high water.

In the Pacific Ocean the tides are very small; but there are not sufficient observations to determine the forms and progress of the cotidal lines. Off Cape Horn, and round the whole shore of Terra-del-Fuego, from the western extremity of Magellan's Strait to Staten Island, it is very remarkable that the tidal wave, instead of following the moon in its diurnal course, travels to the *eastward.* This, however, is a partial phenomenon; and a little farther to the north of the last-named places, the tides set to the north and west. In the Mediterranean and Baltic seas, the tides are inconsiderable, but exhibit irregularities for which it is difficult to account. The Indian Ocean appears to have high water on all sides at once, though not in the central parts at the same time.

13. Since the tides on our coast are derived from the oscillations produced under the direct agency of the sun and moon in the Southern Ocean, and require a certain interval of time for their transfer, it follows that, in general, the tide is not due to the moon's transit immediately preceding, but is regulated by the position which the sun and moon had when they determined the primary tide. The time elapsed between the original formation of the tide and its appearance at any place is called the *age* of the tide, and sometimes, after Bernoulli, the *retard.* On the shores of Spain and North America, the tide is a day and a half old; in the port of London, it appears to be two days and a half old when it arrives.

14. In the open ocean the crest of tide travels with enormous velocity. If the whole surface were uniformly covered with water, the summit of the tide-wave, being mainly governed by the moon, would everywhere follow the moon's transit at the same interval of time, and consequently travel round the earth in a little more than twenty-four hours. But the circumference of the earth at the equator being about 25000 miles, the velocity of propagation would therefore be about 1000 miles per hour. The actual velocity is, perhaps, nowhere equal to this, and is very

different at different places. In latitude 60° south, where there is no interruption from land (except the narrow promontory of Patagonia), the tide-wave will complete a revolution in a lunar day, and travel at the rate of five hundred miles an hour. On examining Dr. Whewell's map of cotidal lines, it will be seen that the great tide-wave from the Southern Ocean travels from the Cape of Good Hope to the Azores in about twelve hours, and from the Azores to the southernmost part of Ireland in about three hours more. In the Atlantic, the hourly velocity in some cases appears to be 10° of latitude, or near 700 miles, which is almost equal to the velocity of sound through the air. From the south point of Ireland to the north point of Scotland, the time is eight hours, and the velocity about 160 miles an hour along the shore. On the eastern coast of Britain, and in shallower water, the velocity is less. From Buchanness to Sunderland it is about sixty miles an hour; from Scarborough to Cromer, thirty-five miles; from the North Foreland to London, thirty miles; from London to Richmond, thirteen miles an hour in that part of the river. (Whewell, *Phil. Trans.* 1833 and 1836.) When we speak of the velocity of the tidal wave, it must not be imagined that the mass of water of which the wave is composed has this velocity. If such were the case, its momentum would be destructive indeed. The motion of the tidal wave is only a particular instance of undulatory motion, which is so often misunderstood, and so frequently imputed to the fluid on which the wave is formed, that it may be worth while here to explain it in general.

15. When we see the waves, produced on the surface of the deep, apparently moving in a certain direction, we are very naturally impressed, in the first instance, with the notion that the sea itself is moving in that direction. We imagine that the same wave, as it advances, is composed of the same water, and that the whole surface of the liquid is in a state of progressive motion. The least reflection, however, on the consequences of such a supposition, will soon convince us that it is unfounded. The ship which floats upon the sea, is not carried forward with the waves. They pass in succession under her, now lifting her on their summits, and then letting her sink in the intermediate abyss. Observe a sea-fowl floating on the water, and the same effect will be witnessed. If the water itself partook of the motion of the waves, the ship and the fowl would each be carried forward as if by a current, and would have the same progressive motion as the liquid. Once on the crest of a wave, there they would constantly remain, and their motion would be as smooth as if they were propelled upon the calm surface of a lake; or if once in the hollow

between wave and wave, there likewise they would continually remain, the one wave always keeping before, and the other behind them.

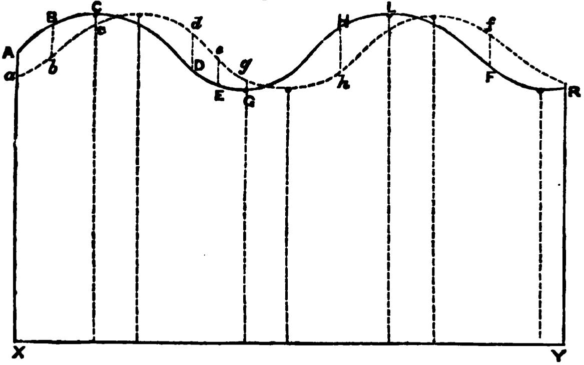
The experiment may be tried upon a tub of water. Let a pebble drop into the centre of it. Rings of waves will immediately be formed round the place where it falls, and they will appear to move outwards from the place of the fall towards the edge of the tub. If a cork be placed anywhere upon the water, it will not be carried by these waves towards the edge of the tub, but will float in the same place, the waves passing successively under it, and the cork rising and sinking as the crest and hollow pass it.

If we observe the waves of the sea breaking on a level strand, we shall soon be convinced that their apparent progressive motion does not affect the water, for if it did, the sea would soon flow in upon the shores, and inundate the adjacent country. So far, however, from the water's partaking of the apparent motion of the waves in approaching the shore, this motion of the waves continues the same even when the water is retiring. If we observe a flat strand when the tide is ebbing, we shall still find the waves moving towards the shore.

16. That this apparent motion of water in a state of undulation is a mere optical illusion we cannot therefore doubt. But we are naturally curious to learn what is the cause of this illusion. That a progressive motion takes place in *something*, we have proof from the evidence of our eyes. That no progressive motion takes place in the liquid we have also proof, from the evidence of our eyes, and from other still more unquestionable testimony. To what then does this progressive motion belong? we answer, to the *form* of the wave, and not to the liquid that composes it.

To make this apparent, let A B C D E, &c. (fig. 4), represent the surface of the sea, C and L being the crests of two successive waves, and G the hollow between them, and let X Y represent the bottom of the sea. After a given interval, ten seconds for example, let the position of the waves be *a b c d e*, &c., the motion being directed from A towards E. Now this motion of the waves is produced in the following manner:—The water which was at A sinks, during the interval of ten seconds, to *a*, the water which was at B sinks to *b*, that which was at C to *c*, that which was at D rises to *d*, that which was at E rises to *e*, that which was at F to *f*, and so on. Thus, in the interval, all parts of the water on one side of a certain point sink, and all those at the other side rise, the extent to which they rise and sink being such, that the surface assumes the new position *a b c d e*, &c. That it is actually the case may be demonstrated by placing on the surface a series of floating bodies, each of

Fig. 4.



which will be observed to rise or sink with the water in the manner here described.

It appears, therefore, that the advance of the wave from A C E to *c d h* is in fact produced not by any advance of the water, but by its different points rising and sinking alternately in the vertical direction. It will thus be understood how the *form* of a wave may actually have a progressive motion, while the water that composes it continues always to hold the same position over the bottom. The real motion of the particles of the liquid by which the waves are produced is an alternate vertical motion upwards and downwards through a height equal to the difference between the level of the crest and the hollow of each wave, or what is the same, through twice the height of the crest of the wave above that level at which the water would settle if it were absolutely quiescent and free from all undulation.

If a cloth were laid loosely over a number of parallel rollers placed at equal distances asunder, so that it would fall between roller and roller, it would represent the form of a series of waves. If a progressive motion were given to the rollers, the cloth being kept stationary, the progressive motion of the waves would be produced;—the cloth would seem to advance.

It is the same cause which makes a revolving cork-screw, held in a fixed position, seem to be advancing in that direction in which it would actually advance if the screw were passing through a cork. The point which is nearest to the eye, and which corresponds to the crest of the wave in the former example, continually occupies a different point of the worm, and continually advances towards its extremity.

This property has been prettily applied and illustrated in clocks for the chimney-piece or console. A round rod of glass, twisted so that a ridge in the form of a screw is produced upon its surface, is inserted in the mouth of some figure, such as a lion or a dolphin, which being supposed to discharge water, forms a fountain. The extremity of the glass rod concealed within the mouth of the figure, is fixed on the axis of a wheel, to which a continual motion of rotation is imparted by the works of the clock, and the other end is concealed in the vessel designed to represent the basin, or reservoir, of the fountain. The constant rotation of the twisted glass rod produces the appearance of a progressive motion from the mouth of the figure to the reservoir, as already explained in the example of the cork-screw, and the rod of glass appears like a stream of water continually issuing from the fountain, and falling into the reservoir.

To return to the phenomena of the tides, it is necessary to observe that there is, nevertheless, a real progressive motion of the water directed up the course of tidal rivers, and upon the flat strands of bays and inlets. This, however, is not the progressive motion of the tide-wave, but that of the water falling from the height to which it has been raised, as it might flow down the side of a declivity.

17. The difference of level between high and low water is affected by various causes, but chiefly by the configuration of the land, and is very different at different places. In deep inbends of the shore, open in the direction of the tide-wave and gradually contracting like a funnel, the convergence of water causes a very great increase of the range. Hence the very high tides in the Bristol Channel, the bay of St. Malo, and the bay of Fundy, where the tide is said to rise sometimes to the height of one hundred feet. Promontories, under certain circumstances, exert an opposite influence, and diminish the magnitude of the tide. The observed ranges are also very anomalous. At certain places on the south-east coast of Ireland, the range is not more than three feet, while at a little distance on each side it becomes twelve or thirteen feet; and it is remarkable that these low tides occur directly opposite the Bristol Channel, where (at Chepstow) the difference between high and low water amounts to sixty feet. In the middle of the Pacific it amounts to only two or three feet. At the London Docks, the average range is about 22 feet; at

Liverpool, 15·5 feet; at Portsmouth, 12·5 feet; at Plymouth, also 12·5 feet; at Bristol, 33 feet.

18. Besides the numerous causes of irregularity depending on the local circumstances, the tides are also affected by the state of the atmosphere. At Brest, the height of high water varies inversely as the height of the barometer, and rises more than eight inches for a fall of about half an inch of the barometer. At Liverpool, a fall of one-tenth of an inch in the barometer corresponds to a rise in the river Mersey of about an inch; and at the London Docks, a fall of one-tenth of an inch corresponds to a rise in the Thames of about seven-tenths of an inch. With a low barometer, therefore, the tide may be expected to be high, and *vice versâ*. The tide is also liable to be disturbed by winds. Sir John Lubbock states, that in the violent hurricane of January 8th, 1839, there was no tide at Gainsborough, which is twenty-five miles up the Trent—a circumstance unknown before. At Saltmarsh, only five miles up the Ouse from the Humber, the tide went on ebbing, and never flowed until the river was dry in some places; while at Ostend, towards which the wind was blowing, contrary effects were observed. During strong north-westerly gales the tide marks high water earlier in the Thames than otherwise, and does not give so much water, while the ebb tide runs out late, and marks lower; but upon the gales abating and weather moderating, the tides put in and rise much higher, while they also run longer before high water is marked, and with more velocity of current: nor do they run out so long or so low.

LUNAR INFLUENCES.

1. Popular opinions on Lunar Influences.—2. Red moon.—3. Time for felling timber.—4. Supposed Lunar Influences on vegetables.—5. On the complexion.—6. On putrefaction.—7. On shell-fish.—8. On the marrow of animals.—9. On the weight of the human body.—10. On births.—11. On incubation.—12. On mental derangement and other human maladies—Instances of this supposed influence during eclipse given by Faber and Ramazzini—Amusing anecdote of a village curé near Paris—Examples of Vallisnieri and Bacon—Observations and examples of Menuret, Hoffmann, Dr. Mead, Pyson, and Dr. Gall.—13. Difficulty of showing fallacy of these opinions by reasoning or proof—Dr. Olbers' partial refutation of them—Arago's opinion on them.—14. General conclusion that few of these influences have any foundation in fact.

1. **Astronomers** have demonstrated that the effects of the moon's gravitation are manifested by various phenomena upon the surface of the earth, among which the most conspicuous are the tides of the ocean. But popular opinion, advancing further, has in all nations, and in all ages, claimed for our satellite a vast number of other influences which do not seem to appertain to its mere physical attraction. The vicissitudes of the weather which have been supposed to follow the course of the lunar phases might be imagined, if they could be shown to have any reality, to be produced by atmospheric tides or currents arising from the

moon's attraction, like the tides of the ocean. We have shown, however, in another number of this series, that there are no grounds whatever, either in theory or in observation, for imputing to the moon any such meteorological influence, and that, as a matter of fact, there is no such accordance or correspondence whatever between the lunar phases and the changes of the weather.

There are, however, a numerous class of other influences which popular opinion has imputed to our satellite, which we propose to examine, and which, however absurd some of them may appear in a scientific point of view, claim to be seriously considered, inasmuch as they have prevailed among mankind in almost all countries and throughout all ages.

According to these popular opinions and traditions, our satellite is responsible for a vast variety of influences on the organised world. The circulation of the sap in vegetables, the qualities of grain, the goodness of the vintage, are severally laid to its account; and timber must be planted, transplanted, and felled, the harvest cut down and gathered in, the juice of the grape expressed, and its subsequent treatment regulated at times and under circumstances having determined relations to the aspects of the moon, if excellence be looked for in these products of the soil. According to popular belief, our satellite also presides over human maladies, and the phenomena of the sick chamber are governed by the lunar phases; nay, the very marrow of our bones and the weight of our bodies suffer increase or diminution under its influence. Nor is its influence limited to mere physical and organic effects; it extends its sway into the region of intellectual phenomena, and notoriously governs mental derangement.

If such doctrines and opinions were limited to particular nations, or prevailed only at particular epochs, they would be less entitled to serious consideration. But it is a curious fact, and one which it is extremely difficult to account for, that many of these doctrines prevail and have prevailed among nations and people so distant and unconnected, that it is impossible to imagine the same errors to have had the same origin. At all events the extent and long continuance of their prevalence entitles them to grave investigation. We propose, therefore, at present to state some of the principal facts and arguments bearing on these points, for the collection of most of which we are indebted to the labours and research of M. Arago.

To analyse all the popular opinions which relate to lunar influences would require a volume. We shall confine ourselves therefore to the principal of them, and shortly examine how far they can be reconciled with the established principles of astronomy and physics.

2. *The Red Moon.*—It is believed generally, especially in the neighbourhood of Paris, that in certain months of the year, the moon exerts a great influence upon the phenomena of vegetation. Gardeners give the name of *Red Moon* to that moon which is full between the middle of April and the close of May. According to them the light of the moon at that season exercises an injurious influence upon the young shoots of plants. They say that when the sky is clear the leaves and buds exposed to the lunar light redden and are killed as if by frost, at a time when the thermometer exposed to the atmosphere stands at many degrees above the freezing point. They say, also, that if a clouded sky intercept the moon's light it prevents these injurious consequences to the plants, although the circumstances of temperature are the same in both cases.

According to the notions of these agriculturists the rays of lunar light are endowed with a certain frigorific property, in the same manner as those of solar light are endowed with a calorific virtue; and that as the latter raise the temperature of objects upon which they are directed, the former, on the contrary, lower their temperature.

Now this question has been submitted to the test of direct experiment, and the result has been directly opposite to such a notion. The bulb of a thermometer sufficiently sensitive to render apparent a change of temperature amounting to the thousandth part of a degree, was placed in the focus of a concave reflector of vast dimensions, which being directed to the moon, the lunar rays were collected with great power upon it. Not the slightest change, however, was produced in the thermometric column, proving that a concentration of rays sufficient to fuse gold, if they proceeded from the sun, does not produce a change of temperature so great as the thousandth part of a degree when they proceed from the moon.

Nevertheless, the fact observed by the gardeners and agriculturists is real, subject only to the objection that their observation of it has not been sufficiently extended. Had they observed the effects produced on clear and clouded nights which are not moonlit, they would have discovered the moon's innocence of the offence they charge against her.

That these phenomena are wrongly ascribed to the influence of the moon, will be easily comprehended by any one who is familiar with the physical principles which govern the radiation and reflection of heat.

All bodies, whatever be the matter of which they are formed, and whatever be their temperature, emit continually rays of heat, just as the sun or any luminous body emits rays of light. The intensity with which this radiation takes place, depends partly on the temperature, partly on the sort of matter, partly on the state of the surface of the body. The higher the temperature, other things being the same, the more intense will be the radiation. Certain sorts of bodies are strong, while others are feeble, radiators. Metallic bodies are examples of the latter, and charcoal of the former. Polished surfaces are unfavourable, rough surfaces favourable to radiation.

All bodies are likewise capable of reflecting from their surfaces the rays of heat which fall upon them. But different bodies possess this quality of reflection in different degrees, according to the state of their surfaces; those which have the greatest power of radiation having the least power of reflection.

A clear and unclouded sky, being in fact empty space, cannot reflect back to the earth any of the heat which is radiated by bodies on the earth; but if the sky be clouded, the heat thus radiated will be reflected back to the earth in a greater or less degree.

If, therefore, the firmament at night be clear and unclouded, all bodies on the surface of the earth radiating heat towards it, and receiving back no part of that heat by reflection, will lose temperature, will become colder; and this fall of temperature will be greater with bodies which are strong radiators than with those which are feeble radiators.

But if the firmament be covered with clouds, the heat which all bodies on the surface of the earth radiate will be reflected back to them by the clouds, and receiving as much or nearly as much as they emit, their temperature will be maintained.

So powerful is the cooling effect of an unclouded sky, that in hot climates water is frozen by such exposure. It is placed in porous earthen pots, under the clear sky. It loses heat at the same time by radiation from its surface, by radiation from the surface of the earthen pan, and by evaporation, especially from the latter surface. The result of these combined effects is, that the water in the pans is congealed, although the temperature of the air and surrounding objects may be considerably above the point of congelation.

The leaves and flowers of plants are always strong radiators of heat, and on a clear and unclouded night they lose temperature continually by this radiation, not receiving at the same time any return by reflection. But if, as has been explained above, the sky be clouded, they will receive as much as they give, and their temperature will not fall.

The moon, therefore, has no connexion whatever with this effect; and it is certain that plants would suffer under the same circumstances whether the moon is above or below the horizon. It equally is quite true that if the moon be above the horizon, the plants cannot suffer unless it be visible; because a *clear sky* is indispensable as much to the production of the injury to the plants as to the visibility of the moon; and, on the other hand, the same clouds which veil the moon and intercept her light, give back to the plants that warmth which prevents the injury here adverted to. The popular opinion is therefore right as to the *effect*, but wrong as to the *cause;* and its error will be at once discovered by showing that on a clear night, when the moon is new, and, therefore, not visible, the plants will be similarly affected.

3. *Time for felling Timber.*—An opinion is generally entertained that timber should be felled only during the decline of the moon; for if it be cut down during its increase, it will not be of good or durable quality. This impression prevails in various countries. It is acted upon in England, and is made the ground of legislation in France. The forest laws of the latter country interdict the cutting of timber during the increase of the moon. M. Auguste de Saint Hilaire states that he found the same opinion prevalent in Brazil. Signor Francisco Pinto, an eminent agriculturist in the province of Espirito Santo, assured him as the result of his experience, that the wood which was not felled at the full of the moon was immediately attacked by worms and very soon rotted.

In the extensive forests of Germany, the same opinion is entertained and acted upon with the most undoubting confidence in its truth. Sauer, a superintendent of some of these districts, assigns what he believes to be its physical cause. According to him, the ascensional force of the sap is much greater during the increase than during the decrease of the moon, and he infers, therefore, that timber which is felled in the first or second quarter of the moon, when the vessels are more filled with sap, will be spongy and more easily attacked by worms; that it will be more difficult to season, and that it will warp and split by exposure to very slight variations of temperature; but that, on the contrary, timber felled in the third or fourth quarter, when the sap ascends with diminished force, will be more dense and durable, and fitter for the purposes of structure.

Can there be imagined in the whole range of natural science a physical relation more extraordinary and unaccountable than this supposed correspondence between the movement of the sap and the phases of the moon? Assuredly theory affords not the slightest countenance to such a supposition: but let us inquire as to the fact, whether it be really the case that the quality of timber depends upon the state of the moon at the time it is felled.

M. Duhamel du Monceau, a celebrated French agriculturist, made direct experiments for the purpose of testing this question; and clearly and conclusively showed that the qualities of timber felled in different parts of the lunar month are the same. M. Duhamel felled a great many trees of the same age, growing from the same soil, and exposed to the same aspect, and never found any difference in the quality of the timber when he compared those which were felled in the decline of the moon with those which were felled during its increase; in general they have afforded timber of the same quality. He adds, however, that by a circumstance, which was doubtless fortuitous, a slight difference was manifested in favour of timber which had been felled between the new and full moon—contrary to popular opinion.

4. *Supposed Lunar Influence on Vegetables.*—It is a maxim among gardeners, that cabbages and lettuces which are desired to shoot forth early, flowers which are to be double, trees which it is desired should produce early ripe fruit, should severally be sown, planted, and pruned during the decrease of the moon; and that, on the contrary, trees which are expected to grow with vigour should be sown, planted, grafted, and pruned during the increase of the moon. These opinions are altogether erroneous. The increase or decrease of the moon has no appreciable influence on the phenomena of vegetation; and the experiments and observations of several French agriculturists, and especially of M. Duhamel du Monceau (already alluded to) have clearly established this.

Montanari has attempted, like M. Sauer, to assign the physical cause for this imaginary effect. During the day, he says, the solar heat augments the quantity of sap which circulates in plants, by increasing the magnitude of the tubes through which the sap moves; while the cold of the night produces the opposite effect by contracting these tubes. Now, at the moment of sunset, if the moon be increasing, it will be above the horizon, and the warmth of its light would prolong the circulation of the sap; but, during its decline, it will not rise for a considerable time after sunset, and the plants will be suddenly exposed to the unmitigated cold of the night, by which a sudden contraction of leaves and tubes will be produced, and the circulation of the sap as suddenly obstructed.

If we admit the lunar rays to possess any sensible calorific power, this reasoning might be allowed; but it will have very little force when it is considered that the extreme change of temperature which can be produced by the lunar light, does not amount to the thousandth part of a degree of the thermometer.

It is a curious circumstance that this erroneous prejudice prevails on the American continent. M. Auguste de Saint Hilaire states, that in Brazil cultivators plant, during the decline of the moon, all vegetables whose roots are used as food, and, on the contrary, they plant during the increasing moon, the sugar-cane, maize, rice, beans, &c., and, in general, those which bear the food upon their stocks and branches. Experiments, however, were made and reported by M. de Chanvalon, at Martinique, on vegetables of both kinds planted at different times in the lunar month, and no appreciable difference in their qualities was discovered.

There are some traces of a principle in the rule adopted by the South American agronomes, according to which they treat the two classes of plants distinguished by the production of fruit on their roots or on their branches differently; but there are none in the European aphorisms. The directions of Pliny are still more specific: he prescribes the time of the full moon for sowing beans, and that of the new moon for lentils. "Truly," says M. Arago, "we have need of a robust faith to admit without proof that the moon, at the distance of 240,000 miles, shall in one position act advantageously upon the vegetation of beans, and that in the opposite position, and at the same distance, she shall be propitious to lentils."

Supposed Lunar Influence on Grain.—Pliny states that if we would collect grain for the purpose of immediate sale, we should do so at the full of the moon; because, during the moon's increase the grain augments remarkably in magnitude: but if we would collect the grain to preserve it, we should choose the new moon, or the decline of the moon.

So far as it is consistent with observations that more rain falls during the increase of the moon than during its decline, there may be some reason for this maxim; but Pliny, or those from whom we receive the maxim, can scarcely have credit for grounds so rational: besides which, the difference in the quantity of rain which falls during the two periods is so utterly insignificant as to be totally incapable of producing the effects here adverted to.

Supposed Lunar Influence on Wine-making.—It is a maxim of wine-growers, that wine which has been made in two moons is never of a good quality, and cannot be clear. Toaldo, the celebrated Italian meteorologist, whose mind appears to have been predisposed for the reception of lunar prejudice, attempts to justify this maxim. "The vinous fermentation," he says, "can only be carried on in two moons when it begins immediately before the new moon: and, consequently, that this being a time when the enlightened side of the moon is turned for the most part from the earth, our atmosphere is deprived of the heat of the lunar rays; that therefore the temperature of the earth is lowered, and the fermentation is less active."

To this we need only answer, that the moon's rays do not affect the temperature of the air to the extent of one thousandth part of a degree of the thermometer, and that the difference of temperatures of any two neighbouring places in which the process of making the wine of the same soil and vintage might be conducted, must be many times greater at any given moment of time, and yet no one ever imagines that such a circumstance can affect the quality of the wine.

According to the meteorological maxims of the ancients, the fate of the vintage was even more powerfully affected by the influence of a particular star, and moreover one scarcely so bright as to be classed among those of the first magnitude, than by that of the moon. This stellar enemy of the grape was the star called Procyon, in the constellation of the little dog. Pliny records the opinion prevailing in his time that Procyon decided the fate of the vintage, and that its malign influence burnt the grape.

Now it might fairly be demanded by what means the grape was protected from this malignant star in some years, though exposed to it in others? Procyon, a fixed star, held and still holds constantly the same place in the firmament; and whatever be the physical influence which it radiates to the earth, that influence cannot change from year to year. If it be replied that the number of unclouded nights at a certain season is greater or less in different years, we shall then fall back upon the explanation already given in the case of the red moon, and show that Procyon is in this case a mere witness, and not a malefactor.

As this ancient error does not, however, appear to prevail in our times, it will not be necessary to enlarge further on this point.

It is a maxim of Italian wine merchants, that wine ought never to be transferred from one vessel to another in the month of January or March, unless in the decline of the moon, under penalty of seeing it spoiled.

Toaldo has not favoured us with any physical reason for this maxim; but it is remarkable that Pliny, on the authority of Hyginus, recommends precisely the opposite course. We may presume that from such contrary rules, it may reasonably be inferred that the moon has no influence whatever in this case.

Among the maxims of Pliny we find that grapes should be dried by night at new moon, and by day at full moon.

When the moon is new it is below the horizon during the night, and above it during the day; and when it is full it is above the horizon during the night, and below it during the day. The maxim of Pliny, therefore, is equivalent to a condition requiring that the grapes should be dried when the moon is below the horizon. It is evident that the absence of the moon is not required in this case in consequence of any effect which her light might produce if she were present; for when the moon is new she affords no light, even when in the firmament, the illuminated side being turned from the earth. If the maxim be founded upon any reason, it must, therefore, either be on some influence which the moon is supposed to produce when present, independent of her light (the absence of which influence is desired), or it may be that she may be supposed to transmit some effect through the solid mass of the earth when on the other side of it which she is incapable of producing without its intervention. The maxim is probably as absurd and groundless as the other effects imputed to the moon.

5. *Supposed Lunar Influence on the Complexion.*—It is a prevalent popular notion in some parts of Europe, that the moon's light is attended with the effect of darkening the complexion.

That light has an effect upon the colour of material substances is a fact well known in physics and in the arts. The process of bleaching by exposure to the sun is an obvious example of this class of facts. Vegetables and flowers which grow in a situation excluded from the light of the sun are different in colour from those which have been exposed to its influence. The most striking instance, however, of the effect of certain rays of solar light in blackening a light-coloured substance, is afforded by chloride of silver, which is a white substance, but which immediately becomes black when acted upon by the rays near the violet extremity of the spectrum. This substance, however, highly susceptible as it is of having its colour affected by light, is, nevertheless, found not to be changed in any sensible degree when exposed to the light of the moon, even when that light is condensed by the most powerful burning lenses. It would seem, therefore, that as far as any analogy can be derived from the qualities of this substance, the popular impression of the influence of the moon's rays in blackening the skin receives no support.

M. Arago (who generally inclined to favour rather than oppose prevailing popular opinions), thought it possible that some effect may be produced upon the skin exposed on clear nights, explicable on the same principle as that by which we have explained the effects erroneously imputed to what is called the *red moon*. The skin being, in common with the leaves and flowers of vegetables, a good radiator of heat, will, when exposed on a clear night, for the same reasons, sustain a loss of temperature. Although this will be to a certain extent restored by the sources of animal heat, still it may be contended that the cooling produced by radiation is not altogether without effect. It is well known that a person who sleeps exposed in the open air on a night when the dew falls, is liable to suffer from severe cold, although the atmosphere around him never falls below a moderate temperature; and although no actual deposition of dew may take place upon his skin. This effect must arise from the constant lowering of temperature of the skin by radiation.

The *Hâle du bivouack* is a term familiar to all French soldiers who have taken much part in campaigns. Hâle is a term which expresses a certain supposed quality of the atmosphere, by which it produces the effect of tanning or darkening the skin. It is well known to the soldier that it takes place only on unclouded nights when the face is exposed to the sky. That it is not a mere quality of the atmosphere is proved by the fact that any screen which will intercept the view of the sky will protect the face, however much it be otherwise exposed to the air.

In the south of France mothers warn their daughters against nocturnal promenades by the old proverb:—

> "Que lou sol y la sereine
> Fan veni la gent mouraine."

It is remarkable that this proverb is current in places where the moon is not noticed as concerned in the effect produced.

6. *Supposed Lunar Influence on Putrefaction.*—Pliny and Plutarch have transmitted it as a maxim, that the light of the moon facilitates the putrefaction of animal substances, and covers them with moisture. The same opinion prevails in the West Indies, and in South America. An impression is prevalent, also, that certain kinds of fish exposed to moonlight lose their flavour and become soft and flabby; and that if a wounded mule be exposed to the light of the moon during the night, the wound will become irritated, and frequently become incurable.

Such effects, if real, may be explained upon the same principles as those by which we have already explained the effects imputed to the red moon. Animal substances exposed to a clear sky at night, are liable to receive a deposition of dew, which humidity has a tendency to accelerate putrefaction. But this effect will be produced if the sky be clear, whether the moon be above the horizon or not. The moon, therefore, in this case, is a witness and not an agent; and we must acquit her of the misdeeds imputed to her.

7. *Supposed Lunar Influence on Shell-fish.*—It is a very ancient remark, that oysters and other shell-fish become larger during the increase than during the decline of the moon. This maxim is mentioned by the poet Lucilius, by Aulus Gellius, and others: and the members of the academy *del Cimento* appear to have tacitly admitted it, since they endeavour to give an explanation of it. The fact, however, has been carefully examined by Rohault, who has compared shell-fish taken at all periods of the lunar month, and found that they exhibit no difference of quality.

8. *Supposed Lunar Influence on the Marrow of Animals.*—An opinion is prevalent among butchers that the marrow found in the bones of animals varies in quantity according to the phase of the moon in which they are slaughtered. This question has also been examined by Rohault, who made a series of observations which were continued for twenty years with a view to test it; and the result was that it was proved completely destitute of foundation.

9. *Supposed Lunar Influence on the Weight of the Human Body.*—Sanctorius, whose name is celebrated in physics for the invention of the thermometer, held it as a principle that a healthy man gained two pounds weight at the beginning of every lunar month, which he lost towards its completion. This opinion appears to be founded on experiments made upon himself; and affords another instance of a fortuitous coincidence hastily generalised. The error would have been corrected if he had continued his observations a sufficient length of time.

10. *Supposed Lunar Influence on Births.*—It is a prevalent opinion that births occur more frequently in the decline of the moon than in her increase. This opinion has been tested by comparing the number of births with the periods of the lunar phases; but the attention directed to statistics as well in this country as abroad, will soon lead to the decision of this question. Other sexual phenomena, vulgarly supposed to have some relation to the lunar month, have no relation whatever to that period.

11. *Supposed Lunar Influence on Incubation.*—It is a maxim handed down by Pliny, that eggs should be put to hatch when the moon is new. In France it is a maxim generally adopted, that the fowls are better and more successfully reared when

they break the shell at the full of the moon. The experiments and observations of M. Girou de Buzareingues have given countenance to this opinion. But such observations require to be multiplied before the maxim can be considered as established. M. Girou inclines to the opinion that during the dark nights about new moon the hens sit so undisturbed that they either kill their young or check their development by too much heat; while in moonlight nights, being more restless, this effect is not produced.

12. *Supposed Lunar Influence on Mental Derangement and other Human Maladies.*—The influence on the phenomena of human maladies imputed to the moon is very ancient. Hippocrates had so strong a faith in the influence of celestial objects upon animated beings, that he expressly recommends no physician to be trusted who is ignorant of astronomy. Galen, following Hippocrates, maintained the same opinion, especially of the influence of the moon. Hence in diseases the lunar periods were said to correspond with the succession of the sufferings of the patients. The critical days or *crises* (as they were afterwards called), were the seventh, fourteenth, and twenty-first of the disease, corresponding to the intervals between the moon's principal phases. While the doctrine of alchymists prevailed, the human body was considered as a microcosm; the heart, representing the vital principle, was placed under the influence of the sun; the brain was regulated and controlled by the moon. The planets had each its proper influence; Jupiter presided over the lungs, Mars over the liver, Saturn over the spleen, Venus over the kidneys, and Mercury over the organs of generation. Of these grotesque notions there is now no relic, except the term *lunacy*, which still designates unsoundness of mind. But even this term may in some degree be said to be banished from the terminology of medicine, and it has taken refuge in that receptacle of all antiquated absurdities of phraseology—the law. Lunatic, we believe, is still the term for the subject who is incapable of managing his own affairs.

Although the ancient faith in the connexion between the phases of the moon and the phenomena of insanity appears in a great degree to be abandoned, yet it is not altogether without its votaries; nor have we been able to ascertain that any series of observations conducted on scientific principles, has ever been made on the phenomena of insanity, with a view to disprove this connexion. We have even met with intelligent and well-educated physicians who still maintain that the paroxysms of insane patients are more violent when the moon is full than at other times.

Mathiolus Faber gives an instance of a maniac who at the very moment of an eclipse of the moon, became furious, seized upon a sword, and fell upon every one around him. Since it was observed that as the day of the eclipse approached, the patient became more and more sombre and melancholy, it may be inferred that in this case imagination, excited by the apprehension of the approaching phenomenon, had more to do with the paroxysm than the moon.

Ramazzini relates that, in the epidemic fever which spread over Italy in the year 1693, patients died in an unusual number on the 21st of January, at the moment of a lunar eclipse. Without disputing this fact (to ascertain which, however, it would be necessary to have statistical returns of the daily deaths), it may be objected that the patients who thus died in such numbers at the moment of the eclipse, might have had their imaginations highly excited, and their fears wrought upon by the approach of that event, if popular opinion invested it with danger. That such an impression was not unlikely to prevail is evident from the facts which have been recorded.

At no very distant period from that time, in August, 1654, it is related that patients in considerable numbers were by order of the physicians shut up in chambers well closed, warmed, and perfumed, with a view to escape the injurious influence of the solar eclipse, which happened at that time; and such was the consternation of persons of all classes, that the numbers who flocked to confession were so great, that the ecclesiastics found it impossible to administer that rite. An amusing anecdote is related of a village curate near Paris, who, with a view to ease the minds of his flock, and to gain the necessary time to get through his business, seriously assured them that the eclipse was postponed for a fortnight.

Two of the most remarkable examples recorded of the supposed influence of the moon on the human body, are those of Vallisnieri and Bacon. Vallisnieri declares that being at Padua recovering from a tedious illness, he suffered on the 12th of May, 1706, during the eclipse of the sun, unusual weakness and shivering. Lunar eclipses never happened without making Bacon faint; and he did not recover his senses till the moon recovered her light.

That these two striking examples should be admitted in proof of the existence of lunar influence, it would be necessary, says M. Arago, to establish the fact that feebleness and pusillanimity of character are never connected with high qualities of mind.

Menuret considers that cutaneous maladies have a manifest connexion with the lunar phases. He says that he himself observed in the year 1760, a patient afflicted with a scald head (*teigne*), who, during the decline of the moon, suffered from a gradual increase of the malady, which continued until the epoch of the new moon, when it had covered the face and breast, and produced insufferable itching. As the moon increased, these symptoms disappeared by degrees; the face became free from the eruption; but the same effects were reproduced after the full of the moon. These periods of the disease continued for three months.

Menuret also stated that he witnessed a similar correspondence between the lunar phases and the distemper of the itch; but the circumstances were the reverse of those in the former case; the malady attaining its maximum at the full of the moon, and its minimum at the new moon.

Without disputing the accuracy of these statements, or throwing any suspicion on the good faith of the physician who has made them, we may observe that such facts prove nothing except the fortuitous coincidence. If the relation of cause and effect had existed between the lunar phases and the phenomena of these distempers, the same cause would have continued to produce the same effect in like circumstances; and we should not be left to depend for the proof of lunar influence on the statements of isolated cases, occurring under the observation of a physician who was himself a believer.

Maurice Hoffman relates a case which came under his own practice, of a young woman, the daughter of an epileptic patient. The abdomen of this girl became inflated every month as the moon increased, and regularly resumed its natural form with the decline of the moon.

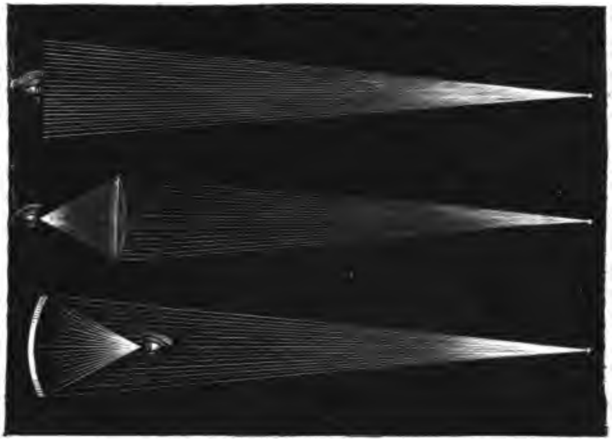
Now, if this statement of Hoffman were accompanied by all the necessary details, and if, also, we were assured that this strange effect continued to be produced for any considerable length of time, the relation of cause and effect between the phases of the moon and the malady of the girl could not legitimately be denied; but receiving the statement in so vague a form, and not being assured that the effect continued to be produced beyond a few months, the legitimate conclusion at which we must arrive is, that this is another example of fortuitous coincidence, and may be classed with the fulfilment of dreams, prodigies, &c., &c.

As may naturally be expected, nervous diseases are those which have presented the most frequent indications of a relation with the lunar phases. The celebrated Mead was a strong believer, not only in the lunar influence, but in the influence of all the heavenly bodies on all the human. He cites the case of a child who always went into convulsions at the moment of full moon. Pyson, another believer, cites another case of a paralytic patient whose disease was brought on by the new moon. Menuret records the case of an epileptic patient whose fits returned with the full moon. The transactions of learned societies abound with examples of giddiness, malignant fever, somnambulism, &c., having in their paroxysms more or less corresponded with the lunar phases. Gall states, as a matter having fallen under his own observation, that patients suffering under weakness of intellect, had two periods in the month of peculiar excitement; and in a work published in London so recently as 1829, we are assured that these epochs are between the new and full moon.

13. Against all these instances of the supposed effect of lunar influence, we have little direct proof to offer. To establish a negative is not easy. Yet it were to be wished that in some of our great asylums for insane patients, a register should be preserved of the exact times of the access of all the remarkable paroxysms; a subsequent comparison of this with the age of the moon at the time of their occurrence would furnish the ground for legitimate and safe conclusions. We are not aware of any scientific physician who has expressly directed his attention to this subject, except Dr. Olbers of Bremen, celebrated for his discovery of the planets Pallas and Vesta. He states that in the course of a long medical practice, he was never able to discover the slightest trace of any connéxion between the phenomena of disease and the phases of the moon. In the spirit of true philosophy, M. Arago, nevertheless, recommends caution in deciding against this influence. The nervous system, says he, is in many instances an instrument infinitely more delicate than the most subtle apparatus of modern physics. Who does not know that the olfactory nerves inform us of the presence ot odoriferous matter in air, the traces of which the most refined physical analysis would fail to detect? The mechanism of the eye is highly affected by that lunar light which, even condensed with all the power of the largest burning lenses, fails to affect by its heat the most susceptible thermometers, or, by its chemical influence, the chloride of silver; yet a small portion of this light introduced through a pin-hole will be sufficient to produce an instantaneous contraction of the pupil; nevertheless the integuments of this membrane, so sensible to light, appear to be completely inert when otherwise affected. The pupil remains unmoved, whether we scrape it with the point of a needle, moisten it with liquid acids, or impart to its surface electric

sparks. The retina itself, which sympathises with the pupil, is insensible to the influence of the most active mechanical agents. Phenomena so mysterious should teach us with what reserve we should reason on analogies drawn from experiments made upon inanimate substances, to the far different and more difficult case of organised matter endowed with life.

14. In conclusion, then, it appears that of all the various influences popularly supposed to be exerted on the surface of the earth, few have any foundation in fact.



Figs. 2, 3, 4.

THE STELLAR UNIVERSE.

◆

CHAPTER I.

1. Retrospect of the solar system.— 2. Inquiries beyond its limits.— 3. This system surrounded by an extensive void.—4. This proved by the absence of external perturbations.—5. And by comets, which are feelers of the system.—6. Where then is the vast multitude of stars which appear in the firmament?—7. Absence of apparent parallax.—8. Illustration of the effects of parallax.—9. Its apparent absence favoured the Ptolemaic system. — 10. Effects of parallax explained.—11. Parallax of the planets visible.

1. In former parts of this series, we have taken a survey of the group of globes which, in company with the earth, revolve round the sun; have reviewed their motions, compared their magnitudes and distances, and explained the numerous analogies having the force of a moral demonstration which prove that they are inhabited worlds, playing in the economy of the universe parts in all respects similar to that of the earth. Passing successively from planet to planet, we have been oppressed by the stupendous dimensions presented to our contemplation. We have seen Jupiter—a globe fourteen hundred times the bulk of the earth—revolving at a distance of five hundred millions of miles from the sun, attended by his four moons:—the Saturnian system, with its globe, a thousand times more voluminous than that of the earth, its vast rings whirling round it, concentrically with each other and with the planet, and shining upon either hemisphere, having the appearance of a

broad silver zone, and its seven moons. We have seen this complex system, sweeping round the sun in a vast orbit, at a distance of a thousand millions of miles, yet preserving such order in its movements that no one member of it overtakes or is overtaken by another,—the planet having a year thirty times the length of ours, diversified by similar seasons, having variations of temperature within limits equal to those of the earth, but varied by seven different kinds of months. Passing to still more remote distances, we encountered Uranus, attended by moons, the number of which has not been ascertained, and probably furnished with other illuminating apparatus, the discovery of which is reserved for future observers. Revolving at eighteen hundred and twenty millions of miles from the sun, we have shown that this planet has a year eighty-four times the length of ours, diversified no doubt by similar seasons, and that, by reason of its enormous distance, the sun appears to its inhabitants as a disc whose diameter is nineteen times less than that which it presents to us.

In fine, having arrived at the extreme limits of the system, we found the planet Neptune, revolving at the distance of two thousand eight hundred and fifty millions of miles from the sun, having a year a hundred and sixty-four times longer than ours. Thus, the seasons of this planet have each forty-one years' duration. By reason of its distance, the apparent diameter of the sun, as seen by its inhabitants, is thirty times less than that which it presents to us; so that the sun appears to them with the same magnitude as that which the planet Venus presents to us when seen under the most favourable aspect.

Thus it appears that the solar system, of which our earth is an individual member, is included within a circle something less than six thousand millions of miles in diameter; and the space within this circle has been surveyed with the most marvellous precision by astronomical observers.

2. This region, however, vast as it is, forms but a small portion of that part of the material universe to which scientific inquiry and research have been extended. The inquisitive spirit of man has not rested content within such limits. Taking its stand at the extremities of the system, and throwing its searching glance towards the interminable realms of space which extend beyond them, it still asks—What lies there? Has the Infinite circumscribed the exercise of his creative power within these precincts—and has He left the unfathomable depths of space that stretch beyond them a wide solitude? Has He whose dwelling is immensity, and whose presence is everywhere and eternal, remained inactive throughout regions compared with which the solar system shrinks into a point?

Even though scientific research should have left us without definite information on these questions, the light which has been shed on the Divine character, as well by reason as by revelation, would have filled us with the assurance that there is no part of space, however remote, which must not teem with evidences of exalted power, inexhaustible wisdom, and untiring goodness.

But science has not so deserted us. It has, on the contrary, supplied us with much interesting information respecting regions of the universe, the extent of which is so great that even the whole dimensions of the solar system supply no modulus sufficiently great to enable us to express their magnitude.

It will not then be unprofitable or unpleasing on the present occasion to extend our inquiries into those realms of space, which stretch beyond the limits of our system, and to inquire into the condition of the physical creation there.

3. We are furnished with a variety of evidence, establishing incontestably the fact, that around the solar system, to a vast distance on every side, there exists an unoccupied space; that the solar system stands alone in the midst of a vast solitude. It has been shown that the mutual gravitation of bodies placed in the neighbourhood of each other is betrayed by its effects upon their motions. If, therefore, there exist beyond the limits of the solar system, and within a distance not so great as to render the attraction of gravitation imperceptible, any mass of matter, such as another sun like our own, such a mass would undoubtedly exercise a disturbing force upon the various bodies of the system. It would cause each of them to move in a manner different from that in which it would have moved if no such body existed.

4. Thus it appears that, even though a mass of matter in our neighbourhood should escape direct observation, its presence would be inevitably betrayed by the effects which its gravitation would produce upon the planets. No such effects, however, are discoverable. The planets move as they would move if the solar system were independent of any external disturbing attraction. These motions are such, and such only, as can be accounted for by the attraction of the sun and the reciprocal attraction of the other bodies of the system. The inference from this is, that there does not exist any mass of matter in the neighbourhood of the solar system within any distance which permits such a mass to exercise upon it any discoverable disturbing influence; and that if any body analogous to our sun exists in the universe, it must be placed at a distance so great, that the whole magnitude of our system will shrink into a point, compared with it.

5. But we have other indications of this condition of things.

The solar system is supplied with *feelers*, which it is enabled to throw out into the regions surrounding it to vast distances, and these are endowed with the highest conceivable susceptibility, which would cause them to betray to us the presence in these regions even of masses of matter of very limited dimensions. These feelers are the COMETS, and in particular one called Halley's comet. This body emerges periodically, and makes an excursion into the surrounding regions to a distance of little less than one thousand millions of miles beyond the limits of our system, and returns at regular intervals to the sun. It is a body of extreme levity and tenuity compared even with the smallest planetary masses; it is, therefore, eminently susceptible of the effects of gravitation proceeding from a body external to it.

We shall show, on another occasion, that when this body, once in seventy-five years, departs from our system to make its vast excursion through distant regions of space, the eye of science pursues it along its path, watches its movements, and follows its course. That course is calculated upon the supposition that it is subject to no attraction through the entire range of its orbit except those of the sun and planets, and the calculations of its return are thus made. The time and the place of each of its successive returns have been foretold; and we have found that they have corresponded faithfully with such predictions. It is certain, then, that in its range through space this body has not passed in the neighbourhood of any mass of matter capable of exercising an observable attraction upon it. In fact, it moves exactly as it would move if no material object existed in the creation save those of the solar system itself. It follows, therefore, that all other objects must be too distant from our system to produce any discoverable attraction even on so light a body as this.

6. Yet when, on any clear night, we contemplate the firmament, and behold the countless multitude of objects that sparkle upon it, remembering what a comparatively small number are comprised among those of the solar system, and even of these how few are visible at any one time, we are naturally impelled to the inquiry, Where in the universe are these vast numbers of objects placed?

Very little reflection and reasoning, applied to the consideration of our own position and to the appearance of the heavens, will convince us that the objects that chiefly appear on the firmament must be at almost immeasurable distances. The earth in its annual course round the sun moves in a circle, the diameter of which is about two hundred millions of miles. We, who observe the heavens, are transported upon it round that vast circle. The station from which we observe the universe at one period of the year is, then, two hundred millions of miles from the station from which we view it at another.

7. Now it is a fact, within the familiar experience of every one, that the relative position of objects will depend upon the point from which they are viewed. If we stand upon the bank of a river, along the margin of which a multitude of ships are stationed, and view the masts of the vessels, they will have among each other a certain relative arrangement. If we change our position, however, through the space of a few hundred yards, the relative position of these masts will not be the same as before. Two which before lay in line will now be seen separate; and two which before were separated are now brought into line. Two, one of which was to the right of the other, are now reversed; that which was to the right, is at the left, and *vice versâ;* nor are these changes produced by any change of position of the ships themselves, for they are moored in stationary positions. The changes of appearance are the result of *our own change of position;* and the greater that change of position is, the greater will be the relative change of these appearances. Let us suppose, however, that we are moved to a much greater distance from the shipping; any change in our position will produce much less effect upon the relative position of the masts; perhaps it will require a very considerable change to produce a perceivable effect upon them. In fine, in proportion as our distance from the masts is increased, so in proportion will it require a greater change in our own position to produce the same apparent change in their position.

8. Thus it is with all visible objects. When a multitude of stationary objects are viewed from a distance, their relative position will depend upon the position of the observer; and if the station of the observer be changed, a change in the relative position of the objects must be expected; and if no perceptible change is produced, it must be inferred that the distance of the objects is incomparably greater than the change of position of the observer.

Let us now apply these reflections to the case of the earth and the stars. The stars are analogous to the masts of the ships, and the earth is the station on which the observer is placed. It might have been expected that the magnitude of the globe, being eight thousand miles in diameter, would produce a change of position of the observer sufficient to cause a change in the relative position of the stars, but we find that such is not the case. The stars, viewed from opposite sides of the globe, present exactly the same appearance; we must, therefore, infer that the diameter of the earth is absolutely nothing compared to their distance.

But the astronomer has still a much larger modulus to fall back upon. He reflects, as has been already observed, that he is enabled to view the stars from two stations separated from each other, not by eight thousand miles, the diameter of the earth, but by two hundred millions of miles, that of the earth's orbit. He, therefore, views the heavens on the 1st of January, and views them again on the 1st of July, the earth having in the meanwhile passed to the opposite side of its orbit, yet he finds, to his amazement, that the aspect is the same. He thinks that this cannot be —that so great a change of position in himself cannot fail to make some change in the apparent position of the stars;—that, although their general aspect is the same, yet when submitted to exact examination a change must assuredly be detected. He accordingly resorts to the use of instruments of observation capable of measuring the relative positions of the stars with the last conceivable precision, and he is more than ever confounded by the fact that still no discoverable change of position is found.

9. For a long period of time this result seemed inexplicable, and accordingly it formed the greatest difficulty with astronomers, in admitting the annual motion of the earth. The alternative offered was this; it was necessary, either to fall back upon the Ptolemaic system, in which the earth was stationary, or to suppose that the immense change of position of the earth in the course of half a year, could produce no discoverable change of appearance in the stars; a fact which involves the inference, that the diameter of the earth's orbit must be a mere point compared with the distance of the nearest stars. Such an idea appeared so inadmissible that for a long period of time many preferred to embrace the Ptolemaic hypothesis, beset as it was with difficulties and contradictions.

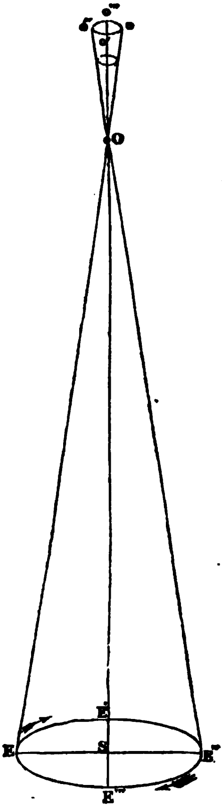
Improved means of instrumental observation and micrometrical measurement, united with the zeal and skill of observers, have at length surmounted these difficulties; and the parallax, small indeed but still capable of measurement, of several stars has been ascertained.

10. To render these results, and the processes by which they have been attained, intelligible, we shall here explain the general effects of annual parallax.

Since the earth moves annually round the sun, as a stationary centre in a circle whose diameter must have the vast magnitude of two hundred millions of miles, all observers placed upon the earth, seeing distant objects from points of view so extremely distant one from the other as are opposite extremities of the same diameter of such a circle, must necessarily, as might be supposed, see these objects in very different directions.

To comprehend the effect which might be expected to be produced upon the apparent place of a distant object by such a motion, let E E′ E″ E‴, fig. 1, represent the earth's annual course round the sun as seen in perspective, and let O be any distant object visible from the earth. The extremity E of the line E O, which is the visual direction of the object, being carried with the earth round the circle E E′ E″ E‴, will annually describe a cone of which the base is the path of the earth, and the vertex is the place of the object O. While the earth moves round the circle E E″, the line of visual direction would therefore have a corresponding motion, and the apparent place of the object would be successively changed with the change of direction of this line. If the object be imagined to be projected by the eye upon the firmament, it would trace upon it a path *o o′ o″ o‴*, which would be circular or elliptical, according to the direction of the object. When the earth is at E, the object would be seen at *o;* and when the earth is at E″, it would be seen at *o″*. The extent of this apparent displacement of the object would be measured by the angle E O E″, which the diameter E E″ of the earth's path or orbit would subtend at the object O.

Fig. 1.



It has been stated that, in general, the apparent displacement of a distant visible object produced by any change in the station from which it is viewed is called PARALLAX. That which is produced by the change of position due to the diurnal motion of the earth being called DIURNAL PARALLAX, the corresponding displacement due to the annual motion of the earth is called the ANNUAL PARALLAX.

The greatest amount, therefore, of the annual parallax for any proposed object is the angle which the semidiameter of the earth's orbit subtends at such object, as the greatest amount of the diurnal parallax is the angle which the semidiameter of the earth itself subtends at the object.

Now, as the most satisfactory evidence of the annual motion of the earth would be the discovery of this displacement, and successive changes of apparent position of all objects on the firmament consequent on such motion, the absence of any such phenomenon must be admitted to constitute, *primâ facie*, a formidable argument against the earth's motion.

11. The effects of annual parallax are observable, and indeed are of considerable amount, in the case of all the bodies composing the solar system. The apparent annual motion of the sun is altogether due to parallax. The apparent motions of the planets and other bodies composing the solar system are the effects of parallax, combined with the real motions of these various bodies.

Until the annual motion of the earth was admitted, these effects of annual parallax on the apparent motions of the solar system were ascribed to a very complicated system of real motions of these bodies, of which the earth was assumed to be the stationary centre, the sun revolving round it, while at the same time the planets severally revolved round the sun as a moveable centre. This hypothesis, proposed originally by Apollonius of Perga, a Grecian astronomer, some centuries before the birth of Christ, received the name of the PTOLEMAIC SYSTEM, having been developed and explained by PTOLEMY, an Egyptian astronomer who flourished in the second century, and whose work, entitled "Syntaxis," obtained great celebrity, and for many centuries continued to be received as the standard of astronomical science.

Although Pythagoras had thrown out the idea that the annual motion of the sun was merely apparent, and that it arose from a real motion of the earth, the natural repugnancy of the human mind to admit a supposition so contrary to received notions prevented this happy anticipation of future and remote discovery from receiving the attention it merited; and Aristotle, less sagacious than Pythagoras, lent the great weight of his authority to the contrary hypothesis, which was accordingly adopted universally by the learned world, and continued to prevail, until it was overturned in the middle of the sixteenth century by the celebrated Copernicus, who revived the Pythagorean hypothesis of the stability of the sun and the motion of the earth.

The hypothesis proposed by him in a work entitled "De Revolutionibus Orbium Cœlestium," published in 1543, at the moment of his death, is that since known as the COPERNICAN SYSTEM, and, being now established upon evidence sufficiently demonstrative to divest it of its hypothetical character, is admitted as the exposition of the actual movements by which that part of the universe called the solar system is affected.

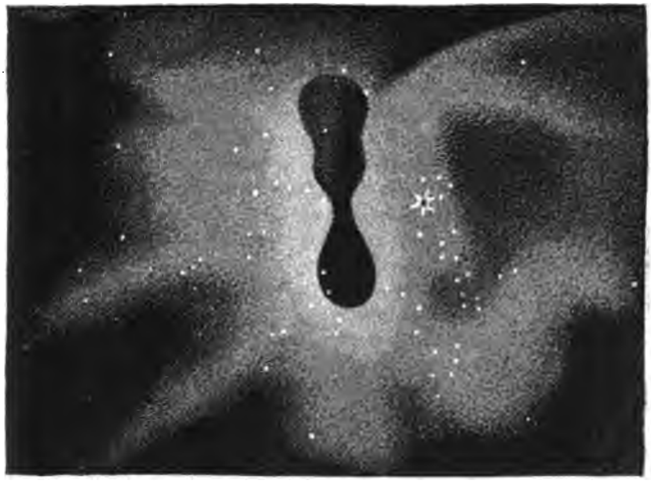


Fig. 62.—TELESCOPIC VIEW OF PART OF THE GREAT NEBULA IN THE CONSTELLATION OF ARGO.

THE STELLAR UNIVERSE.

CHAPTER II.

12. Absence of parallax obstructed the acceptance of the Copernican system.—13. Immense distance of stars inferred from its minuteness or absence.—14. Its greatest possible magnitude.—15. Distances of stars inferred.—16. Use of the motion of light as a modulus of this distance.—17. Methods of ascertaining the parallax.—18. Parallax of α Centauri.—19. Parallax of nine principal stars.—20. The vacuum surrounding the solar system necessary to cosmical order.—21. Classification of stars by magnitude arbitrary.—22. Fractional magnitudes.—23. Number of stars of each magnitude.—24. Total number of stars in the firmament.—25. Varieties of magnitude chiefly caused by difference of distance.—26. Stars as distant from each other as from the sun.—27. Telescopes do not magnify them.—28. Absence of a disc proved by their occultations.—29. Meaning of the term magnitude as applied to the stars.—30. Why the stars may be rendered imperceptible by their distance.—31. Real magnitudes of the stars.—32. Application of photometers or astrometers.—33. Comparison of the sun's light with that of a star.—34. Relative real magnitudes of the sun and a star estimated.—35. Comparative magnitude of the sun and the dog-star.—36. Vast use of the telescope in stellar observations.—37. Its power to increase the apparent splendour of a star explained.

12. THE greatest difficulty against which the Copernican system has had to struggle, even among the most enlightened of its oppo-

nents, has been the absence of all apparent effects of parallax among the fixed stars, those objects which are scattered in such countless numbers over every part of the firmament. From what has been explained, it will be perceived that, supposing these bodies to be, as they evidently must be, placed at vast distances outside the limits of the solar system, and in every imaginable direction around it, the effects of annual parallax would be to give to each of them an apparent annual motion in a circle or ellipse, according to their direction in relation to the position of the earth in its orbit, the ellipse varying in its eccentricity with this position, and the diameter of the circle or major axis of the ellipse being determined by the angle which the diameter E E' (fig. 1) of the earth's orbit subtends at the star, which will be less the greater the distance of the star, and *vice versâ*. The apparent position of the star in this circle or ellipse would be evidently always in the plane passing through the star and the line joining the sun and earth.

13. Since then, with a few exceptions, which will be noticed hereafter, no traces of the effects of annual parallax have been discovered among the innumerable fixed stars by which the solar system is surrounded; and since, nevertheless, the annual motion of the earth in its orbit rests upon a body of evidence, and is supported by arguments which must be regarded as conclusive, the absence of parallax can only be ascribed to the fact, that the stars generally are placed at distances from the solar system, compared with which the orbit of the earth shrinks into a point; and, therefore, that the motion of an observer round this orbit, vast as it may seem compared with all our familiar standards of magnitude, produces no more apparent displacement of a fixed star, than the motion of an animalcule round a grain of mustard-seed would produce upon the apparent direction of the moon or sun.

The visual ray by which a star is seen, and which is its apparent direction, is carried by the annual motion of the earth round the surface of a cone, of which the earth's orbit is the base, and of which the star is the apex. The line drawn from the centre of the earth's orbit to the star, is the axis of this cone; and, consequently, the parallax of the star is the angle under the latter line, and the visual ray by the motion of which the surface of the cone is formed.

The same optical effect would be produced by transferring the orbital motion of the earth to the star, the observer being supposed to be stationary, and placed at the centre of the earth's orbit; and this supposition will render all the parallactic phenomena much more easily comprehended. Let the star, then, be imagined to move in a circle equal and parallel to the earth's orbit, the centre of the circle being the true place of the star. The place of the star in this circle of parallax must always be diametrically opposite to the corresponding place of the earth in its orbit. The star so moving would suffer exactly the same apparent displacement as it would appear to suffer if it were, as it is, at rest in its true place, the earth moving in its proper orbit round the sun.

14. It might be supposed, that where the character and laws of the phenomena are so clearly understood, the discovery of their existence could present no great difficulty. Nevertheless, nothing in the whole range of astronomical research has more baffled the efforts of observers than this question of the parallax. This has arisen altogether from the extreme minuteness of its magnitude. It is quite certain that the parallax does not amount to so much as 1″ in the case of any of the numerous stars which have been as yet submitted to the course of observation which is necessary to discover the parallax. Now, since in the determination of the exact uranographical position of a star there are a multitude of disturbing effects to be taken into account and eliminated, such as precession, nutation, aberration, refraction, and others, besides the proper motion of the star, which will be explained hereafter; and since, besides the errors of observation, the quantities of these are subject to more or less uncertainty, it will astonish no one to be told that they may entail, upon the final result of the calculation, an error of 1″; and, if they do, it is vain to expect to discover such a residual phenomenon as parallax, the entire amount of which is less than 1″.

15. If in any case the parallax could be determined, the distance of the stars could be immediately inferred. For, if this value of the parallax be expressed in seconds, or in decimals of a second, and if R denote the semidiameter of the earth's orbit, D the distance of the star, and P the parallax, we shall have

$$\mathrm{D} = \mathrm{R} \times \frac{206265}{\mathrm{P}}.$$

If, therefore, $\mathrm{P} = 1''$, the distance of the star would be 206265 times the distance of the sun, and since it may be considered satisfactorily proved, that no star which has ever yet been brought under observation has a parallax greater than this, it may be affirmed that the nearest star in the universe to the solar system is at a distance, *at least*, 206265 times greater than that of the sun.

Let us consider more attentively the import of this conclusion. The distance of the sun, expressed in round numbers (which are sufficient for our present purpose), is 95 millions of miles. If this be multiplied by 206265, we shall obtain,—not indeed the distance of the nearest of the fixed stars,—but the *minor limit* of that distance, that is to say, a distance within which the star cannot lie. This limit, expressed in miles, is

$$\text{D} = 206265 \times 95{,}000000 = 19{,}595175{,}000000 \text{ miles,}$$

or nearly *twenty billions of miles.*

16. In the contemplation of such numbers the imagination is lost, and no other clear conception remains, except of the mere arithmetical expression of the result of the computation. Astronomers themselves, accustomed as they are to deal with stupendous numbers, are compelled to seek for units of proportionate magnitude to bring the arithmetical expression of the quantities within moderate limits. The motion of light supplies one of the most convenient moduli for this purpose, and has, by common consent, been adopted as the unit in all computations whose object is to gauge the universe. It is known that light moves at the rate of 192000 miles per second. If, then, the distance D above computed be divided by 192000, the quotient will be the time, expressed in seconds, which light takes to move over that distance. But since even this will be an unwieldy number, it may be reduced to minutes, hours, days, or even to years.

In this manner we find that, if any star have a parallax of 1″, it must be at such a distance from our system, that light would take 3·234 years, or three years and eighty-five days, to come from it to the earth.

If the space through which light moves in a year be taken, therefore, as the unit of stellar distance, and P be the parallax expressed in seconds, or decimals of a second, we shall have

$$\text{D} = \frac{3{\cdot}234}{\text{P}}.$$

17. It will easily be imagined that astronomers have diligently directed their observations to the discovery of some change of apparent position, however small, produced upon the stars by the earth's motion. As the stars most likely to be affected by the motion of the earth are those which are nearest to the system, and therefore probably those which are brightest and largest, it has been to such chiefly that this kind of observation has been directed; and since it was certain that, if any observable effect be produced by the earth's motion at all, it must be extremely small, the nicest and most delicate means of observation were those alone from which the discovery could be expected.

One of the earlier expedients adopted for the solution of this problem, was the erection of a telescope, of great length and power, in a position permanently fixed, attached, for example, to the side of a pier of solid masonry, erected upon a foundation of rock. This instrument was screwed into such a position that particular stars, as they crossed the meridian, would necessarily pass within its field of view. Micrometric wires were, in the usual manner, placed in its eye-piece, so that the exact point at which the stars passed the meridian each night, could be observed and recorded with the greatest precision. The instrument being thus fixed and immovable, the transits of the stars were noted each night, and the exact places where they passed the meridian recorded. This kind of observation was carried on through the year; and if the earth's change of position, by reason of its annual motion, should produce any effect upon the apparent position of the stars, it was anticipated that such effect would be discovered by these means. After, however, making all allowance for the usual causes which affect the apparent position of the stars, no change of position was discovered which could be assigned to the earth's motion.

18. Notwithstanding the numerous difficulties which beset the solution of this problem, by means of observations made with the ordinary instruments, Professor Henderson, during his residence, as astronomer at the Royal Observatory, at the Cape of Good Hope, succeeded in making a series of observations upon the star designated α in the constellation of the Centaur, which, being afterwards submitted by him to the proper reductions, gave a parallax of 1″. Subsequent observations made by his successor, Mr. Maclear, at the same observatory, partly with the same instrument, and partly with an improved and more efficient one of the same class, have fully confirmed this result, giving 0·9128, or $\frac{10}{11}$ths of a second as the parallax.

It is worthy of remark, that this conclusion of Messrs. Henderson and Maclear is confirmed in a remarkable manner by the fact, that like observations and computations, applied to other stars in the vicinity of α Centauri, and therefore subject to like annual causes of apparent displacement, such as the mean annual variation of temperature, gave no similar result, showing thus that the displacement found in the case of α Centauri could only be ascribed to parallax.

Since the limits of error of this species of observation affecting the final result cannot exceed the tenth of a second, it may then be assumed as proved, that the parallax of α Centauri is 1″, and, consequently, that its distance from the solar system is such that light must take 3·234 years to move over it.

19. Notwithstanding the great multitude of stars to which instruments of observation of unlooked-for perfection, in the hands of the most able and zealous observers, have been directed, the results of all such labours have hitherto been rather negative than positive. The means of observation have been so perfect, and their

application so extensive, that it may be considered as proved by the absence of all measureable displacement consequent upon the orbital motion of the earth, that, a very few individual stars excepted, the vast multitude of bodies which compose the universe, and which are nightly seen glittering in the firmament, are at distances from the solar system greater than that which would produce an apparent displacement amounting to the tenth of a second. This limit of distance is therefore, ten parallactic units, or about two million times the space between the earth and sun.

Within this limit, or very little beyond it, nine stars have been found to be placed, the nearest of which is that already mentioned, of which Professor Henderson discovered the parallax. Those of the others are due to the observations of Messrs. Bessel, Struve, and Peters. In the following table the parallaxes of these stars are given, with their corresponding distances, expressed in parallactic units, and also in the larger unit presented by the distance through which light moves in a year.

The parallax of the first seven of these stars may be considered as having been ascertained with tolerable certainty and precision. The very small amount of that of the last two is such as to render it more doubtful. What is certain, however, in relation to these is, that the actual amount of their parallax is less than the tenth of a second.

TABLE.

Nine stars, with their ascertained parallax and corresponding distances.

Star.	Parallax.	Distance.		Observer.
		Sun's dist.=1.	Annual motion of light=1.	
α Centauri ...	0·913"	225920	3·54217	Henderson.
61 Cygni... ...	0·348	592715	9·29310	Bessel.
α Lyræ	0·261	790287	12·39080	Struve.
Sirius	0·230	896804	14·06087	Henderson.
1830 Groombridge	0·226	912677	14·30973	Peters.
ι Ursæ	0·133	1550864	24·31579	Peters.
Arcturus	0·127	1624134	25·46456	Peters.
Polaris	0·067	3078582	48·26866	Peters.
Capella	0·046	4484021	70·30435	Peters.

It appears, then, that of the vast multitudes of stars to which the labours of observers have been directed, there are not more than nine which are near enough to our system to be sensibly affected in their apparent directions by the orbital motion of the earth; and that the greatest change produced in the direction of any of these, when seen from opposite sides of the earth's orbit, does not amount to quite so much as one second; while, for those least affected, it does not amount to so much as the tenth of a second; and the necessary inference is, that the nearest of the stars which are scattered in such countless numbers over the heavens, is at a distance over which light would take three years and a-half to pass, moving during that interval through two hundred thousand miles in each second of time.

20. The solar system is, consequently, surrounded in every direction, above, below, and on every side, by a vast abyss, in which no masses of matter, bearing any analogy to the sun or planets, are found; and, indeed, the physical necessity of such a surrounding vacuum will be evident, when it is considered that the proximity of any such masses to the solar system would, by reason of their disturbing forces, throw that system into utter confusion; that it would derange the succession and limits of seasons for all the worlds composing it; would expose them to extremes of temperature incompatible with organised life; and would, ere long, bring them into destructive and fatal collision with each other, or with the masses in their neighbourhood.

We see, therefore, that if Omnipotence has withdrawn the exertion of its creative power from the realms of space which immediately surround us, it has not done so without good and beneficent reasons, and that there is as much to admire in the absence of such manifestation of power in these regions, as in its presence elsewhere.

21. The most inattentive observer of the heavens will be struck with the fact, that the multitude of stars which are presented to his view vary extremely in splendour. Some few might be imagined to shed a perceptible light, and are truly magnificent objects, even when viewed only by the naked eye; while others are so minute and faint, as to be barely perceptible. Between these extremes there are infinite gradations; and astronomers, in adopting a classification, encounter the same difficulty as is presented in every other case in which, for the purposes of science, natural objects are required to be distributed in a limited number of distinct groups. Nature has, in all cases, created them as individuals, distinguished one from another by infinitely minute and faint gradations and characters, while our limited faculties compel us to contemplate them, and reason upon them, as though

they existed in distinct classes. Such classification must, therefore, be to a great extent arbitrary, the individuals placed at the bottom of one class being just as well entitled to a place at the top of the next.

Astronomers, accordingly, in the classification of the visible stars, in the order of their relative splendour, have encountered a like difficulty. The ancient astronomers, by common consent, distributed all the stars visible to the naked eye into six orders of what they called magnitude. The most splendid stars were said to be stars of the first magnitude: the next in the order of splendour, of the second magnitude; and so on to the sixth, which included the stars barely perceptible with the naked eye. As may be expected, from what has been stated, much difference between astronomer and astronomer arose in settling this classification. It necessarily occurred, that numerous stars had such brightness as would equally entitle them to be placed at the foot of the stars of the first magnitude, or at the head of those of the second magnitude. A still greater number raised a like question as to their title to a place in the classes of the second and third magnitude, and so on. Notwithstanding these vague and uncertain conditions, the ancient classification has still maintained its place, and has been accepted by modern astronomers as the least inconvenient in principle, and, as will presently appear, they have even extended the principle, defective as it is, to the far more numerous classes of stars which the telescope has rendered visible.

22. An expedient has occasionally been adopted by observers aiming at more than usual precision to distinguish stars whose brightness renders it doubtful to which of two succeeding magnitudes they ought to be assigned, consisting of a fraction annexed to the number which designates the higher of the two orders. Thus, for example, a star whose brightness appears to give it equal titles to be placed at the foot of those of the second, or the head of those of the third magnitude, is designated as a star of the $2\frac{1}{2}$ magnitude.

Modern observers have also extended the ancient classification to seven orders of magnitude; dividing the ancient stars of the sixth magnitude into two, designated the sixth and the seventh magnitudes; so that, according to the classification received at present, the most minute stars visible to the naked eye, under the most favourable atmospheric conditions at midnight, when all interference of solar light is removed, are classed as stars of the seventh magnitude.

We must here, however, observe, that we fall again into the difficulties arising from arbitrary classification, since certain stars are visible to some eyes, which, at the same time and place, are invisible to others without telescopic aid. Strictly speaking, therefore, stars of the seventh magnitude may be considered as holding an intermediate and doubtful place between those which can and those which cannot be seen by the naked eye.

Having thus explained generally the classification of stars according to their relative apparent splendour, we are now to state the total number of each class scattered over the entire firmament.

23. According to the most accredited catalogue, that of Argelander, the total number of stars from the first to the sixth magnitude inclusive, observed in the northern hemisphere, has been as follows:—

1st Magnitude	9
2nd ditto	34
3rd ditto	96
4th ditto	214
5th ditto	550
6th ditto	1439
Total number	2342

24. Owing to the absence of an equal number of observers in southern latitudes, that hemisphere has not been so accurately surveyed; but it has been ascertained, that it contains 914 stars, from the first to the sixth magnitude inclusive, within 36° of the celestial equator. If it be supposed, as is highly probable, that the stars are distributed in the same proportion over the remainder of the southern hemisphere, it will follow that the total number of stars of the first six orders of magnitude, distributed over the entire firmament from pole to pole, amounts to 4100. If to this be added the probable number of stars of the seventh magnitude, which cannot be so exactly ascertained by direct observation, it will appear that the total number of stars, distributed over the heavens of such a magnitude as to be seen by the best eyes, under the most favourable atmospheric circumstances, is about 6000.

The number of these objects, as they would be estimated by a mere coup d'œil of the heavens, would appear to be vastly greater than this; and even the calculations of some astronomers, allowing a much larger number for the stars of the seventh magnitude, make the total double the number we have here assigned to it.

25. Are we to suppose, then, that this relative brightness which we perceive, really arises from any difference of intrinsic splendour between the objects themselves? or does it, as it may equally do, arise from their difference of distance? Are the stars of the seventh magnitude so much less bright and conspicuous

than those of the first magnitude, because they are really smaller orbs placed at the same distance? or because, being intrinsically equal in splendour and magnitude, the distance of those of the seventh magnitude is so much greater than the distance of those of the first magnitude that they are diminished in their apparent brightness? We know that by the laws of optics the light received from a luminous object diminishes in a very rapid proportion as the distance increases. Thus, at double the distance it will be four times less, at triple the distance it will be nine times less, at a hundred times the distance it will be ten thousand times less, and so on.

It is evident, then, that the great variety of lustre which prevails among the stars may be indifferently explained, either by supposing them objects of different intrinsic brightness and magnitude, placed at the same distance; or objects generally of the same order of magnitude, placed at a great diversity of distances.

Of these two suppositions, the latter is infinitely the more probable and natural; it has, therefore, been usually adopted: and we accordingly consider the stars to derive their variety of lustre almost entirely from their places in the universe being at various distances from us.

26. Taking the stars generally to be of intrinsically equal brightness, various theories have been proposed as to the positions which would explain their appearance; and the most natural and probable is, that their distances from each other are generally equal, or nearly so, and correspond with the distance of our sun from the nearest of them. In this way the fact that a small number of stars only appear of the first magnitude, and that the number increases very rapidly as the magnitude diminishes, is easily rendered intelligible.

If we imagine a person standing in the midst of a wood, surrounded by trees on every side and at every distance, those which immediately surround him will be few in number, and by proximity will appear large. The trunks of those which occupy a circuit beyond the former, will be more numerous, the circuit being wider, and will appear smaller, because their distance is greater. Beyond these again, occupying a still wider circuit, will appear a proportionally augmented number, whose apparent magnitude will again be diminished by increased distance; and thus the trees which occupy wider and wider circuits at greater and greater distances will be more and more numerous, and will appear continually smaller. It is the same with the stars; we are placed in the midst of an immense cluster of suns, surrounding us on every side at inconceivable distances. Those few which are placed immediately about our system, appear bright and large, and we call them *stars of the first magnitude*. Those which lie in the circuit beyond, and occupy a wider range, are more numerous and less bright; and we call them stars of the second magnitude. And there is thus a progression increasing in number and distance and diminishing in brightness, until we attain a distance so great that the stars are barely visible to the naked eye. This is the limit of vision. It is the limit of the range of the eye in its natural condition; but an eye has been given us more potent still, and of infinitely wider range,—the eye of the mind. The telescope, a creature of the understanding, has conferred upon the bodily eye an infinitely augmented range, and, as we shall presently see, has enabled us to penetrate into realms of the universe, which, without its aid, would never have been known to us. But let us, however, pause for the present, and dwell for a moment upon that range of space which comes within the scope of natural vision.

27. A planet, to the naked eye, with one or two exceptions, appears like a common star. The telescope, however, immediately presents it to us with a distinct circular disc, similar to that which the moon offers to the naked eye; and in the case of some of the planets, a powerful telescope will render them apparently even larger than the moon. But the effect is very different indeed when the same instrument is directed even to the brightest star. We find that instead of magnifying, it actually diminishes. There is an optical illusion produced when we behold a star, which makes it appear to us to be surrounded with a radiation which causes it to be represented, when drawn on paper, by a dot with rays diverging on every side from it. The effect of the telescope is to cut off this radiation, and present to us the star as a mere *lucid point*, having no sensible magnitude; nor can any augmented telescopic power which has yet been resorted to, produce any other effect. Telescopic powers, amounting to 6000, were occasionally used by Sir William Herschel, and he stated that with these the apparent magnitude of the stars seemed *less*, if possible, than with lower powers.

28. We have other proofs of the fact, that the stars have no sensible discs, among which may be mentioned the remarkable effect called the occultation of a star by the dark edge of the moon. When the moon is a crescent, or in the quarters, as it moves over the firmament, its dark edge successively approaches to, or recedes from, the stars. And from time to time it happens that it passes between the stars and the eye. If a star had a sensible disc in this case, the edge of the moon would gradually cover it, and the star, instead of being instantaneously extinguished, would gradually disappear. This is found not to be the case;

the star preserves all its lustre until the moment it comes into contact with the dark edge of the moon's disc, and then it is instantly extinguished, without the slightest appearance of diminution of its brightness.

29. It may be asked then, if such be the case, and if none of the stars, great or small, have any discoverable magnitude at all, with what meaning can we speak of stars of the first, second, or other orders of magnitude? The term magnitude thus applied, was used before the invention of the telescope, when the stars, having been observed only with the naked eye, were really supposed to have different magnitudes. We must accept the term now to express, not the comparative magnitude, but the comparative brightness of the stars. Thus, a star of the first magnitude means of the greatest apparent brightness; a star of the second magnitude, means that which has the next degree of splendour, and so on. But what are we to infer from this singular fact, that no magnifying power, however great, will exhibit to us a star with any sensible magnitude? must we admit that the optical instrument loses its magnifying power when applied to the stars, while it retains it with every other visible object? Such a consequence would be eminently absurd. We are therefore driven to an inference regarding the magnitude of stars, as astonishing and almost as inconceivable as that which was forced upon us respecting their distances. We saw that the entire magnitude of the annual orbit of the earth, stupendous as it is, was nothing compared to the distance of one of those bodies, and, consequently, if that orbit were filled by a sun, whose magnitude would therefore be infinitely greater than that of ours, such a sun would not appear to an observer at the nearest star of greater magnitude than 1″; consequently, would have no magnitude sensible to the eye, and would appear as a mere lucid point to an observer at the star! We are then prepared for the inference respecting the fixed stars which telescopic observations lead to. The telescope of Sir William Herschel, to which he applied a power of 6000, did undoubtedly magnify the stars 6000 times, but even then their apparent magnitude was inappreciable. We are then to infer that the distance of these wonderful bodies is so enormous, compared with their actual magnitude, that their apparent diameter, seen from our system, is above 6000 times less than any which the eye is capable of perceiving.

30. It appears, therefore, that stars are rendered sensible to the eye, not by subtending a sensible angle, but by the light they emit. It has been already explained,* that an illuminated or

---

* See Tract on "The Eye."

luminous object—such, for example, as the sun—has the same apparent brightness at all distances; and, consequently, that the quantity of light which the eye of an observer receives from it being in the exact ratio of the apparent area of its visible disc, is inversely as the square of its distance. It remains, however, to explain how it can be that, after it ceases to have a disc of sensible diameter, it does not cease to be visible. This arises from the fact, that the luminous point constituting the image on the retina, is intrinsically as bright as when that image has a large and sensible magnitude. The eye is therefore sensible to the light, though not sensible to the magnitude of the image; and it continues to be sensible to the light, until by increase of distance the light which enters the pupil, and is collected on the retina, though still as intense in its brilliancy as before, is so small in its *quantity*, that it is insufficient to produce sensation.

31. Since it is certain that no body shining like a planet, with borrowed light, could be visible at all, even with the aid of a telescope, at distances far less than those which intervene between the solar system and the nearest of the stars, it follows that the stars must be self-shining bodies like our sun; or, what is the same, that our sun is only one individual unit of the vast number of stars, which are scattered through the universe. This being admitted, a question of much interest and importance arises, to determine not merely the distance of our sun from surrounding suns, and the distances of surrounding suns from each other, but also the comparative magnitude or splendour of these numerous suns, relatively to our own and to each other.

32. One of the most essential data for the solution of this problem, is a sufficiently exact numerical estimate of the comparative apparent lustre of the stars as they appear to the eye, relatively to the sun and to each other. Various instruments have accordingly been invented called *Photometers* or *Astrometers*, which have attained this object with more or less precision. Without entering into the details of the principle or construction of such instruments, we may here state that by their means, the proportion of the quantity of light transmitted to the eye by the sun or moon, or by either of these objects, and a star, or by different stars, compared together, can be ascertained.

By such means, Sir J. Herschel compared the full moon with certain fixed stars, and ascertained, by a mean of eleven observations, that its lustre bore to that of the star α Centauri, which he selected as the standard star of the first magnitude, the ratio of 27408 to 1; in other words, he showed that a cluster consisting of 27408 stars equal in brightness to that of α Centauri would give the same light as the full moon.

Dr. Wollaston, by certain photometric methods, which are considered to have been susceptible of great precision, compared the light of the sun with that of the full moon, and found that the ratio was 801072 to 1; or in other words, that to obtain moonlight as intense in its lustre as sun-light, it would be necessary that 801072 full moons should be stationed in the firmament together.

33. By the combination of these observations of Herschel and Wollaston, we are supplied with means of bringing into direct numerical comparison the sun and the star α Centauri. Since it appears that the light of α Centauri is 27408 times less than that of the full moon, while the light of the full moon is 801072 times less than that of the sun, it will evidently follow, that the light received by the eye from the sun, is greater than that received from the star in the proportion of 801072 times 27408 to 1. Thus, it appears that the light received from the sun, is in round numbers 21956 million times the light received from this particular star, which has been adopted as a fair average standard of stars of the first magnitude.

34. It has been demonstrated by theory, and verified by experiment, that when a luminous object is removed from the eye to increasing distances, the light which the eye receives from it will decrease in the same proportion as the square of the distance increases: that is, at twice the distance, the light is decreased to one fourth; at three times the distance, to a ninth; at four times the distance, to a sixteenth, and so on.

Now, upon this principle, it will be easy to compute the proportion in which the apparent light of the sun would be diminished by any given increase of distance; or, what increase of distance would produce any given decrease of light. Let it then, be demanded how far the sun should be removed from the observer, in order that its light should be decreased in the proportion of 21956 millions to 1, that is so that its light should be equal to that of the star α Centauri. According to what has been just explained, this increase of distance will be found by taking the square root of 21956 millions, which is 148175. It follows, therefore, that if the sun were removed to 148175 times its present distance, it would appear as a star precisely similar to the star α Centauri.

But it has been already shown that this particular star is at a distance 225920 times that of the sun, and, consequently, it follows, that if the sun were removed to that distance, its lustre would be less than that of α Centauri, in the proportion of the square of 148175 to the square of 225920, which is in the proportion of 22 to 51.

Since then, the sun placed beside the star α Centauri, both being at the same distance from the observer, would appear less bright than the star in the proportion of 22 to 51, or 1 to $2\frac{1}{3}$, it follows, that the star α Centauri is a sun more than twice the superficial magnitude of ours, supposing that its luminous surface has the same lustre.

35. Sir J. Herschel found that the lustre of the dog-star is four times that of α Centauri; but according to what has been given in the table in page 182, the distance of the dog-star called *Sirius*, from our system is 896087 times that of the sun. Now from these data, it will be easy to calculate the relative magnitudes of our sun and the dog-star.

Since the light received from the dog-star is four times that received from α Centauri, while the light received from the latter is 21956 million times less than that received from the sun, it follows, that the light received from the dog-star is 5489 million times less than the light received from the sun. Let us now imagine the sun removed to the distance of the dog-star, and let us consider what would then be the light received from it. The distance of the dog-star being 896087 times that of the sun, the sun removed to that distance, would shine with a light less than its present light, in the proportion of the square of 896087 to 1, which is in the proportion of 802972 millions to 1. But from what has been stated above, it appears that the dog-star at the same distance, shines with a light less than the sun in the proportion of 5489 millions to 1. It follows, therefore, that the sun and the dog-star, being placed at the same distance from the observer, the lustre of the dog-star would exceed that of thesun in the proportion of 802972 to 5489, or $146\frac{1}{4}$ to 1;* from which we arrive at the surprising conclusion, that, supposing the surface of Sirius to have a lustre equal to that of the surface of the sun, its surface must be $146\frac{1}{4}$ times greater than that of the sun, so that this stupendous globe of light would have a diameter 12·09 times greater than that of our sun; and, since the diameter of the latter is 882000 miles, that of Sirius would be 10,663380 miles.

36. Since no telescope, however great might be its power, has ever presented a fixed star with a sensible disk, it might be inferred that, for the purposes of stellar investigations, the importance of that instrument must be inferior to that which it may claim in other applications. Nevertheless it is certain, that in no department of physical science has the telescope produced such

---

* Sir John Herschel makes the proportion 63·02, which is certainly incorrect, that being the ratio of the brightness of Sirius to that of α Centauri, and not that of Sirius to the sun; see Herschel's Astronomy, p. 553, edition 1849.

wonderful results as in its application to the analysis of the starry heavens.

Two of the chief conditions necessary to distinct vision are, first, that the image on the retina shall have sufficient magnitude; or, what is equivalent to this, that the object or its image shall subtend at the eye a visual angle of sufficient magnitude; and, secondly, it must be sufficiently illuminated. When, by reason of their distance from the observer, visible objects fail to fulfil either or both of these conditions, the telescope is capable of re-establishing them. It augments the visual angle by substituting for the distant object, which the observer cannot approach, an optical image of it close to his eye, which he can approach; and it augments the illumination by collecting, on each point of such image, as many rays as can enter the aperture of the object glass, instead of the more limited number which can enter the pupil of the naked eye; allowance, nevertheless, being made for the light lost by reflection from the surfaces of the lenses, and by the imperfect transparency of their material.

37. Although no telescope hitherto constructed has ever presented to an observer the optical image of a star, so as to be seen with any sensible visual angle, such image always appearing as a mere lucid point, it is capable, nevertheless, of increasing the brilliancy of that point in an immense proportion. The way in which it accomplishes this, is easily explained. If the eye be imagined to be directed to a star, as shown in fig. 2, the number of rays diverging from that star, and consequently its apparent brightness, will be limited by, and proportional to the magnitude of the pupil. But if the pencil of rays, before arriving at the eye, be received upon the object glass of a refracting telescope, as shown in fig. 3, or upon the concave reflector of a reflecting telescope, as shown in fig. 4, they will be made to converge to a point, and by proper expedients, the eye being placed near that point, instead of receiving only so many rays, as are proportionate to the dimensions of the pupil, will receive all, or nearly all the rays which pass through the object glass, or which are reflected from the concave speculum. Thus, the intensity of the light received from the object will, by such an instrument, be augmented very nearly in the proportion of the square of the diameter of the pupil to the square of the diameter of the object glass or speculum. Taking, for example, the diameter of the object-glass at 12 inches; and that of the pupil a little less than the eighth of an inch, the former will be about 100 times the latter; and it will consequently augment the light received by the eye, in the proportion of about 10000 to 1.

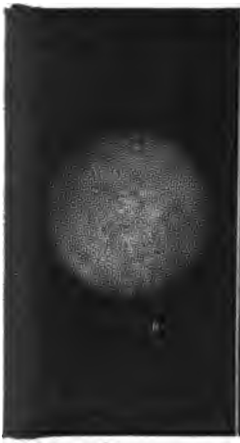


Fig. 52.*

A ROUND NEBULA, OBSERVED AND DRAWN BY SIR J. HERSCHEL.

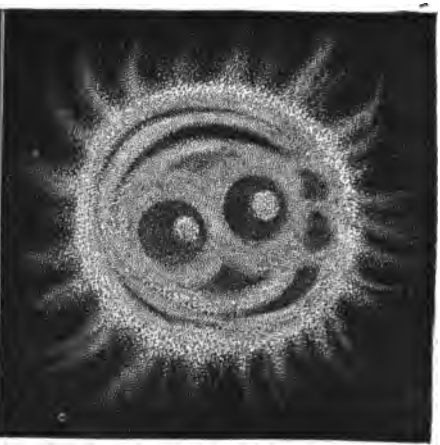


Fig. 53.*

THE SAME OBJECT, AS SHOWN IN LORD ROSSE'S GREAT TELESCOPE.

THE STELLAR UNIVERSE.

◆

CHAPTER III.

38. Telescopic stars.—39. Space-penetrating power of the telescope.—40. Vast distances of small telescopic stars. Periodic Stars: 41. Stars of variable lustre.—42. Remarkable stars of this kind in Cetus and Perseus.—43. Table of periodic stars.—44. Hypothesis to explain Periodic stars. Temporary Stars: 45. Such stars seen in ancient times.—46. Star discovered by Mr. Hind.—47. Missing stars. Double Stars: 48. Researches of Sir W. and Sir J. Herschel.—49. Stars optically double.—50. This supposition not admissible.—51. Refuted by the proper motion.—52. Classification of double stars.—53. Table of double stars.—54. Coloured double stars.—55. Triple and other multiple stars.—56. Attempt to discover parallax by double stars.—57. Observations of Sir W. Herschel.

38. In the preceding paragraphs, our observations have been limited to those stars which are visible to the naked eye. But the power of the telescope to augment in an indefinite proportion the light received by the eye from such an object, obviously supplies the means of rendering stars visible, which, by reason of their extreme distance, transmit light of too small a quantity to affect the retina in any sensible degree. We have seen that stars

---

* The objects are here drawn upon a larger scale than in the original figures, in order to render their details more distinct. The same enlargement of scale has been made in figs. 17, 18, 19, 20, 29, 30, 41, 42, 43, 44, 45, 46, 57, 58.

of the seventh magnitude are only visible under the most favourable atmospheric conditions, and by the sharpest eyes; now, if we suppose these stars, or others similar to them, to be placed at twice their distance, the light they transmit will be diminished in a fourfold proportion; and since at their actual distance they were barely visible, they will be evidently invisible at the augmented distance. But if we suppose a telescope directed to them, which has the power of increasing the light transmitted to the eye in a fourfold proportion, they will, when seen through it, appear exactly as stars of the seventh magnitude; and if the telescope be capable of increasing the light in a greater proportion, they will appear as stars of a still greater magnitude.

In like manner, if we suppose stars of the seventh magnitude removed to three times their present distance, their light would be diminished in a ninefold proportion. But a telescope which would increase the light transmitted to the eye in a ninefold proportion, would make such stars appear like those of the seventh magnitude.

By following the same supposition, we may imagine stars of the seventh magnitude to be removed successively to four, five, six, &c. times their present distance, when their light would be decreased in a sixteen-fold, twenty-five-fold, and thirty-six-fold, &c. proportion, so that all would be removed far beyond the limits of visibility by the naked eye. But if telescopes be successively directed to such stars, which are capable of increasing the light received from them in a sixteen-fold, twenty-five-fold, thirty-six-fold, &c. proportion, they will be all seen as stars of the seventh magnitude.

Although it be highly probable, if not certain, that the innumerable suns, which appear to us as stars, have different real magnitudes, we may, in taking them in large collections, assume that their average magnitude is the same or nearly so, since it is in the highest degree improbable, that the small suns would be all placed at the greatest distances from the solar system, while the large suns would be placed nearest to it. Assuming, then, that the average magnitude of the stars taken in large collections is uniform, it will follow, that their succession of distances will be proportional to the square roots of the powers of the telescopes, which are capable of collecting sufficient light from them to give them the appearance of stars of a given magnitude, the seventh, for example, as seen with the naked eye.

39. Such was the principle which inspired Sir W. Herschel with the stupendous idea of gauging the universe. He contrived to vary the power of his telescopes to collect the light of the stars in such a manner as to bring into view, successively, those which filled regions of space between given limits of distance.

This is what has been called the *space-penetrating power* of the telescope.

If the light of a star of the sixth magnitude be 100 times less than that of a star of the first magnitude, a telescope which would augment the light 100 times, would exhibit it with the same apparent brightness as a star of the first magnitude.

Thus, for example, the reflecting telescope used by Sir William Herschel, in some of his principal stellar researches, had an aperture of eighteen inches, and twenty feet focal length, with a magnifying power of 180. The space-penetrating power of this instrument was found to be seventy-five, the meaning of which is, that when directed to a star of any given brightness, it would augment its brightness so as to make it appear the same as it would be if at seventy-five times less distance, or what is the same, that a star which to the naked eye would appear of the same brightness as that star does when seen in the telescope would require to be removed to seventy-five times the actual distance, so that when seen through the telescope it would have the brightness it has when seen with the naked eye. Thus a star of the sixth magnitude, if removed to seventy-five times the actual distance, would appear in such an instrument still as a star of the sixth magnitude would to the naked eye; and if we assume with Sir John Herschel, that a star of the sixth magnitude has a hundred times less light than α Centauri, and is therefore at ten times a greater distance, it will follow that α Centauri would require to be removed to 750 times its actual distance, so that when viewed through such telescope it would be seen as a star of the sixth magnitude is to the naked eye.

40. If, then, it be assumed, as it may fairly be, that among the innumerable stars which are beyond the range of unaided vision, and brought into view by the telescope, a large proportion must have the same magnitude and intrinsic brightness as the average stars of the first magnitude, it will follow that these must be at distances 750 times greater than the distance of an average star of the first magnitude, such as α Centauri. But it has been already shown that the distance of α Centauri is such that light would require 3·54217 years to come from it to the earth. It would therefore follow, that the distance of the telescopic stars just referred to, must be such that light would take to come from them to the earth

$$3{\cdot}54217 \times 750 = 2656{\cdot}6275 \text{ years.}$$

If it be desired to ascertain the distance of such stars, taking the earth's distance from the sun as the unit, we shall have

$$225920 \times 750 = 169{,}440000.$$

It appears, therefore, that the distance of such a star would be about one hundred and seventy million times the distance of the sun; and since the distance of the sun expressed in round numbers is one hundred millions of miles, it will follow that the distance of such a star is seventeen thousand billions of miles.

We arrive, therefore, at the somewhat astonishing conclusion that the distance of these objects, the existence of which the telescope alone has disclosed to us, must be such that light, moving at the rate of 192000 miles per second, takes upwards of 2600 years to come from them to us, and consequently that the objects we now see are not those which now exist, but those which did exist 2600 years ago; and it is within the scope of physical possibility that they may have changed their conditions of existence, and consequently of appearance, or even have ceased to exist altogether, more than 2000 years ago, although we actually see them at this moment.

This incidentally shows that the actual perception of a visible object is no conclusive evidence of its present existence. It is only a proof of its existence at some anterior period.

It appears, then, that there are numerous orders of stars, which by reason of their remoteness are invisible to the naked eye, but which are rendered visible by the telescope; and these stars are, like those visible to the naked eye, of an infinite variety of degrees of magnitude and brightness, and have accordingly been classed by astronomers according to an order of magnitudes in numerical continuation of that which has been somewhat indefinitely or arbitrarily adopted for the visible stars. Thus, supposing that the last order of stars visible without telescopic aid is the seventh, the first order disclosed by the telescope will be the eighth, and from these the telescopic stars, decreasing in magnitude, have been denominated the ninth, tenth, eleventh, &c. to the sixteenth, or seventeenth magnitude, the last being the smallest stars which are capable of being rendered distinctly visible by the most powerful telescope.

Besides bringing within the range of observation objects placed beyond the sphere which limits the play of natural vision, the telescope has greatly multiplied the number of objects visible within that sphere, by enabling us to see many rendered invisible by their minuteness, or confounded with others by their apparent proximity. Among the stars also which are visible to the naked eye, there are many, respecting which the telescope has disclosed circumstances of the highest physical interest, by which they have become more closely allied to our system, and by which it is demonstrated that the same material laws which coerce the planets, and give stability, uniformity, and harmony to their motions, are also in operation in the most remote regions of the universe.

We shall first notice some of the most remarkable discoveries respecting individual stars, and shall afterwards explain those which indicate the arrangement, dimensions, and form of the collective mass of stars which compose the visible firmament, and the results of those researches which the telescope has enabled astronomers to make in regions of space still more remote.

PERIODIC STARS.

41. The stars in general, as they are stationary in their apparent positions, are equally invariable in their apparent magnitudes and brightness. To this, however, there are several remarkable exceptions. Stars have been observed, sufficiently numerous to be regarded as a distinct class, which exhibit periodical changes of appearance. Some undergo gradual and alternate increase and diminution of magnitude, varying between determinate limits, and presenting these variations in equal intervals of time. Some are observed to attain a certain maximum magnitude, from which they gradually and regularly decline until they altogether disappear. After remaining for a certain time invisible, they re-appear and gradually increase till they attain their maximum splendour, and this succession of changes is regularly and periodically repeated. Such objects are called PERIODIC STARS.

42. The most remarkable of this class is the star called *Omikron*, in the neck of the Whale, which was first observed by David Fabricius, on the 13th August, 1596. This star retains its greatest brightness for about fourteen days, being then equal to a large star of the second magnitude. It then decreases continually for three months until it becomes invisible. It remains invisible for five months, when it re-appears, and increases gradually for three months until it recovers its maximum splendour. This is the general succession of its phases. Its entire period is about 332 days. This period is not always the same, and the gradations of brightness through which it passes are said to be subject to variation. Hevelius states that, in the interval between 1672 and 1676, it did not appear at all.

Some recent observations and researches of M. Argelander, render it probable that the period of this star is subject to a variation which is itself periodical, the period being alternately augmented and diminished to the extent of twenty-five days. The variations of the maximum lustre are also probably periodical.

The star called *Algol*, in the head of *Medusa*, in the constellation of *Perseus*, affords a striking example of the rapidity with which these periodical changes sometimes succeed each other. This star generally appears as one of the second magnitude; but an interval of seven hours occurs at the expiration of every sixty-two, during the first three hours and a half of which it gradually diminishes in brightness till it is reduced to a star of the fourth magnitude, and during the remainder of the interval it again gradually increases until it recovers its original magnitude. Thus, if we suppose it to have attained its maximum splendour at midnight on the first day of the month, its changes would be as follows:—

D.	H.	M.		D.	H.	M.	
0	0	0	to	2	14	0	It appears of second magnitude.
2	14	0	to	2	17	24	It decreases gradually to fourth magnitude.
2	17	24	to	2	20	48	It increases gradually to second magnitude.
2	20	48	to	5	10	48	It appears of second magnitude.
5	10	48	to	5	14	12	It decreases to fourth magnitude.
5	14	12	to	5	17	36	It increases to second magnitude.
			&c.				&c. &c.

This star presents an interesting example of its class, as it is constantly visible, and its period is so short that its succession of phases may be frequently and conveniently observed. It is situate near the foot of the constellation *Andromeda*, and lies a few degrees north-east of three stars of the fourth magnitude, which form a triangle.

Goodricke, who discovered the periodic phenomena of *Algol* in 1782, explained these appearances by the supposition that some opaque body revolves round it, being thus periodically interposed between the earth and the star, so as to intercept a large portion of its light.

The more recent observations on this star indicate a decrease of its period, which proceeds with accelerated rapidity. Sir J. Herschel thinks that this decrease will attain a limit, and will be followed by an increase, so that the variation of the period will prove itself to be periodic.

The stars δ in *Cepheus* and β in *Lyra* are remarkable for the regular periodicity of their lustre. The former passes from its least to its greatest lustre in thirty-eight hours, and from its greatest to its least in ninety-one hours. The changes of lustre of the latter, according to the recent observations of M. Argelander, are very complicated and curious. Its entire period is 12 days 21 hrs. 53 min. 10 sec., and in that time it first increases in lustre, then decreases, then increases again, and then decreases, so that it has two maxima and two minima. At the two maxima its lustre is that of a star of the 3·4 magnitude, and at one of the minima its lustre is that of a star of the 4·3, and at the other that of a star of the 4·5 magnitude. In this case also the period of the star is found to be periodically variable.

43. In the following Table the stars periodically variable, discovered up to 1848, are given, with their periods and extremes of lustre. This Table has been collected from various astronomical records by Sir J. Herschel.

PERIODIC STARS.

No.	Star.	Period.	Change of Magnitude.		Discovered by
		d. dec.	from	to	
1	β Persei (Algol) . .	2·8673	2	4	Goodricke, 1782.
2	λ Tauri	4±	4	5·4	Baxendell, 1848.
3	δ Cephei	5·3664	3·4	5	Goodricke, 1784.
4	η Aquilæ	7·1763	3·4	4·5	Pigott, 1784.
5	* Cancri R.A. (1800)=8^h $32{\cdot}5^m$ N.P.D. 70° 15′	9·015	7·8	10	Hind, 1848.
6	ζ Geminorum . . .	10·2	4·3	4·5	Schmidt, 1847.
7	β Lyræ	12·9119	3·4	4·5	Goodricke, 1784.
8	α Herculis	63±	3	4	Herschel, 1796.
9	59 B.Scuti R.A.(1801)=18^h 37^m N.P.D.=95° 57′	71·200	5	0	Pigott, 1795.
10	ε Aurigæ	250±	3	4	Heis, 1846.
11	ο Ceti (Mira)	331·63	2	0	Fabricius, 1596.
12	* Serpentis R. A. (1828) =15^h 46^m 45^s; N.P. D. 74° 20′ 30″ .	335±	7 ?	0	Harding, 1826.
13	χ Cygni	396·875	6	11	Kirch, 1687.
14	υ Hydræ (B.A.C. 4501) .	494±	4	10	Maraldi, 1704.
15	* Cephei (B.A.C. 7582) .	5 or 6 years	3	6	Herschel, 1782.
16	34 Cygni (B.A.C. 6990). .	18 years ±	6	0	Janson, 1600.
17	* Leonis (B.A.C. 3345) .	Many years	6	0	Koch, 1782.
18	κ Sagittarii	Ditto	3	6	Halley, 1676.
19	ψ Leonis	Ditto	6	0	Montanari, 1667.
20	η Cygni	Ditto	4·5	5·6	Herschel, Jun., 1842?
21	* Virginis R. A. (1840)= 12^h 3^m N.P.D. 82° 8′	145 days	6·7	0	Harding, 1814.
22	* Coronæ Bor. (B.A.C. 5236)	10½ months	6	0	Pigott, 1795.
23	7 Arietis (B.A.C. 581) .	5 years ?	6	8	Piazzi, 1798.
24	η Argûs	Irregular	1	4	Burchell, 1827.
25	α Orionis	Irregular	1	1·2	Herschel, Jun., 1836.
26	α Ursæ majoris . . .	Some years	1·2	2	Ditto, 1846.
27	η Ursæ majoris . .	Ditto	1·2	2	Ditto, 1846.
28	β Ursæ minoris . . .	2 or 3 years ?	2	2·3	Struve, 1838.
29	α Cassiopeiæ . . .	225 days ?	2	2·3	Herschel, Jun., 1838.
30	α Hydræ	29 or 30 days ?	2·3	3	Ditto, 1837.
31	* R. A. (1847)=22^h 58^m $57{\cdot}9^s$ N. P. D.=80° 17′ 30″ . .	Unknown	8 ?	0	Hind, 1848.
32	* R. A. (1848) = 7^h 33^m $55{\cdot}2^s$ N. P. D.=66° 11′ 56″ . .	Ditto	9	0	Ditto, 1848.
33	* R. A. (1848) = 7^h 40^m $10{\cdot}3^s$ N. P. D. = 65° 53′ 29″ . .	Ditto	9	0	Ditto, 1848.
34	Near * R. A. 22^h 21^m $0{\cdot}4^s$ (1848) N.P.D.=100° 42′ 40″ . .	Ditto	7·8	0	Rümker.
35	* R. A. (1848) 14^h 44^m $39{\cdot}6^s$ N. P. D. 101° 45′ 25″ . . .	Ditto	8	9·10	Schumacher.
36	δ Ursæ majoris . .	Many years	2 ?	2·3	Matter of general remark.

N.B. In the above list the letters B. A. C. indicate the catalogue of the British Association, B. the catalogue of Bode. Numbers before the name of the constellation (as 34 Cygni) denote Flamsteed's stars. Since this Table was drawn up, four additional stars, variable from the 8th or 9th magnitude to 0, have been communicated to us by Mr. Hind, whose places are as follow: (1.) R. A. 1^h 38^m 24^s; N. P. D. 81° 9′ 39″; (2.) 4^h 50^m 42^s, 80° 6′ 36″ (1846); (3.) 8^h 43^m 8^s, 86° 11′ (1800); (4.) 22^h 12^m 9^s, 82° 59′ 24″ (1800). Mr. Hind remarks that about several variable stars some degree of haziness is perceptible at their minimum. Have they clouds revolving round them as planetary or cometary attendants? He also draws attention to the fact that the red colour predominates among variable stars generally. The double star, No. 2718 of Struve's Catalogue, R. A. 20^h 34^m P. D. 77° 54′, is stated by Sir John Herschel to be variable. Captain Smyth (Celestial Cycle, i. 274) mentions also 3 Leonis and 18 Leonis as variable, the former from 6^m to 0, Period 78 days, the latter from 5^m to 10^m, Period 311^d 23^h, but without citing any authority. Piazzi sets down 96 and 97 Virginis and 38 Herculis as variable stars.

In the case of many of the stars in the preceding Table, the variations of lustre are subject to considerable irregularities. Thus No. 13 was scarcely visible from 1698, for the interval of three years, even at the epochs when it ought to have had its greatest lustre. The extremes of lustre of No. 9 are also very variable and irregular. In general the variations of No. 22 are so inconsiderable as to be scarcely perceivable, but they become sometimes suddenly so great that the star wholly disappears. The variations of No. 25 were very conspicuous from 1836 to 1840, and again in 1849, being much less so in the intermediate time.

44. Several explanations have been proposed for these appearances.

1. Sir W. Herschel considered that the supposition of the existence of spots on the stars similar to the spots on the sun, combined with the rotation of the stars upon axes, similar to the rotation of the sun and planets, afforded so obvious and satisfactory an explanation of the phenomena, that no other need be sought.

2. Newton conjectured that the variation of brightness might be produced by comets falling into distant suns and causing temporary conflagrations. Waiving any other objection to this conjecture, it is put aside by its insufficiency to explain the periodicity of the phenomena.

3. Maupertius has suggested that some stars may have the form of thin flat disks, acquired either by extremely rapid rotation on an axis, or other physical cause. The ring of Saturn affords an example of this, within the limits of our own system, and the

modern discoveries in nebular astronomy offer other examples of a like form. The axis of rotation of such a body might be subject to periodical change like the nutation of the earth's axis, so that the flat side of the luminous disk might be presented more or less towards the earth at different times, and when the edge is so presented, it might be too thin to be visible. Such a succession of phenomena are actually exhibited in the case of the rings of Saturn, though proceeding from different causes.

4. Mr. Dunn * has conjectured that a dense atmosphere surrounding the stars, in different parts more or less pervious to light, may explain the phenomena. This conjecture, otherwise vague, indefinite, and improbable, totally fails to explain the periodicity of the phenomena.

5. It has been suggested that the periodical obscuration or total disappearance of the star, may arise from *transits* of the star by its attendant planets. The transits of Venus and Mercury are the basis of this conjecture.

The transits of none of the planets of the solar system, seen from the stars, could render the sun a periodic star. The magnitudes, even of the largest of them, are altogether insufficient for such an effect. To this objection it has been answered that planets of vastly greater comparative magnitude may revolve round other suns. But if the magnitude of a planet were sufficient to produce by its transit these considerable obscurations, it must be very little inferior to the magnitude of the sun itself, or at all events, it must bear a very considerable proportion to the magnitude of the sun; in which case it may be objected that the predominance of attraction necessary to maintain the sun in the centre of its system could not be secured. To this objection it is answered, that although the planet may have a great comparative *magnitude*, it may have a very small comparative *density*, and the gravitating attraction depending on the actual mass of matter, the predominance of the solar mass may be rendered consistent with the great relative magnitude of the planet by supposing the density of the one vastly greater than that of the other. The density of the sun is much greater than the density of Saturn.

6. It has been suggested that there may be systems in which the central body is a planet attended by a lesser sun revolving round it as the moon revolves round the earth, and in that case the periodical obscuration of the sun may be produced by its passage once in each revolution behind the central planet.

Such are the various conjectures which have been proposed to explain the periodic stars; and as they are merely conjectures, scarcely deserving the name of hypotheses or theories, we shall leave them to be taken for what they are worth.

---

* Phil. Trans. vol. lii.

TEMPORARY STARS.

Phenomena in most respects similar to those just described, but exhibiting no recurrence, repetition, or periodicity, have been observed in many stars. Thus, stars have from time to time appeared in various parts of the firmament, shone with extraordinary splendour for a limited time, and have then disappeared and have never again been observed.

45. The first star of this class which has been recorded, is one observed by *Hipparchus*, 125 B.C., the disappearance of which is said to have led that astronomer to make his celebrated catalogue of the fixed stars; a work which has proved in modern times of great value and interest. In the 389th year of our era, a star blazed forth near α *Aquilæ*, which shone for three weeks, appearing as splendid as the planet Venus, after which it disappeared and has never since been seen. In the years 945, 1264, and 1572, brilliant stars appeared between the constellations of *Cepheus* and *Cassiopeia*. The accounts of the positions of these objects are obscure and uncertain, but the intervals between the epochs of their appearances being nearly equal, it has been conjectured that they were successive returns of the same periodic star, the period of which is about 300 years, or possibly half that interval.

The appearance of the star of 1572 was very remarkable, and having been witnessed by the most eminent astronomers of that day, the account of it may be considered to be well entitled to confidence. Tycho Brahe, happening to be on his return on the evening of the 11th November from his laboratory to his dwelling-house, found a crowd of peasants gazing at a star which he was sure did not exist half an hour before. This was the temporary star of 1572, which was then as bright as the dog-star, and continued to increase in splendour until it surpassed Jupiter when that planet is most brilliant, and finally it attained such a lustre, that it was visible at mid-day. It began to diminish in December, and altogether disappeared in March, 1574.

On the 10th October, 1604, a splendid star suddenly burst out in the constellation of *Serpentarius*, which was as bright as that of 1572. It continued visible till October, 1605, when it vanished.

46. A star of the fifth magnitude, easily visible to the naked eye, was seen by Mr. Hind in the constellation of Ophiuchus, on the night of the 28th April, 1848. From the perfect acquaint-

ance of that observer with the region of the firmament in which he saw it, he was quite certain that, previous to the 5th April, no star brighter than those of the ninth magnitude had been there, nor is there any star in the catalogues at all corresponding to that which he saw there on the 28th. This star continued to be seen until the advance of the season and its low altitude rendered it impossible to be observed. It, however, constantly diminished in lustre until it disappeared, and has not since been seen.

47. To the class of temporary stars may be referred the cases of numerous stars which have disappeared from the firmament. On a careful examination of the heavens, and a comparison of the objects observed with former catalogues, and of catalogues ancient and modern with each other, many stars formerly known are now ascertained to be missing; and although, as Sir John Herschel observes, there is no doubt that in many instances these apparent losses have proceeded from mistaken entries, yet it is equally certain that in numerous cases there can have been no mistake in the observation or the entry, and that the star has really existed at a former epoch, and certainly has since disappeared.

When we consider the vast length of many of the periods of astronomical phenomena, it is far from being improbable that these phenomena, which seem to be occasional, accidental, and springing from the operation of no regular physical causes, such as those indicated by the class of variable stars first considered, may after all be periodic stars of the same kind, whose appearances and disappearances are brought about by similar causes. All that can be certainly known respecting them is, that they have appeared or disappeared once in that brief period of time within which astronomical observations have been made and recorded. If they be periodic stars, the length of whose period exceeds that interval, their changes could only have been once exhibited to us, and after ages have rolled away, and time has converted the future into the past, astronomers may witness the next occurrence of their phases, and discover that to be regular, harmonious, and periodic, which appears to us accidental, occasional, and anomalous.

DOUBLE STARS.

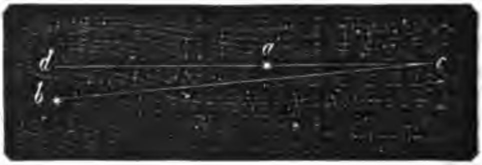
When the stars are examined individually by telescopes of a certain power, it is found that many which to the naked eye appear to be single stars, are in reality two stars placed so close together that they appear as one. These are called *double stars.*

48. A very limited number of these objects had been discovered

before the telescope had received the vast accession of power which was given to it by the labour and genius of Sir William Herschel. That astronomer observed and catalogued 500 double stars; and subsequent observers, among whom his son, Sir John Herschel, holds the foremost place, have augmented the number to 6000.

49. The close apparent juxta-position of two stars in the firmament is a phenomenon which might be easily explained, and which could create no surprise. Such an appearance would be produced by the accidental circumstance of the lines of direction of the two stars as seen from the earth, forming a very small angle, in which case, although the two stars might in reality be as far removed from each other as any stars in the heavens, they would nevertheless *appear* close together. The fig. 5 will render this easily understood. Let *a* and *b* be the two stars seen from *c*. The star *a* will be seen relatively to *b*, as if it were at *d*, and the two objects will seem to be in close juxta-position; and if the angle under the lines *c a* and *c b* be less than the sum of the apparent semi-diameters of the stars, they would actually appear to touch.

Fig. 5.



50. If such objects were few in number, this mode of explaining them might be admitted; and such may, in fact, be the cause of the phenomenon in some instances. The chances against such proximity of the lines of direction are however so great as to be utterly incompatible with the vast number of double stars that have been discovered, even were there not, as there is, other conclusive proof that this proximity and companionship is neither accidental nor merely apparent, but that the connection is real, and that the objects are united by a physical bond analogous to that which attaches the planets to the sun.

But apart from the proofs of real proximity which exist respecting many of the double stars, and which will presently be explained, it has been shown that the probability against mere optical juxta-position such as that described above is almost infinite. Professor Struve has shown that, taking the number of stars whose existence has been ascertained by observation down to the 7th magnitude inclusive, and supposing them to be scattered fortuitously over the entire firmament, the chances against any two of them having a position so close to each other as 4" would be 9570 to 1. But when this calculation was made, considerably more than 100 cases of such duple juxta-position were ascertained to exist. The same astronomer also calculated that the chances against a third star falling within 32" of the first two would be 173524 to 1; yet the firmament presents at least four such triple combinations.

Among the most striking examples of double stars may be mentioned the bright star *Castor*, which, when sufficiently magnified, is proved to consist of two stars between the third and fourth magnitudes, within five seconds of each other. There are many, however, which are separated by intervals less than one second; such as ε *Arietis*, *Atlas Pleiadum*, γ *Coronæ*, η and ζ *Herculis*, and τ and λ *Ophiuchi*.

51. Another argument against the supposition of mere fortuitous optical juxta-position, unattended by any physical connection, is derived from a circumstance which will be fully explained hereafter. Certain stars have been ascertained to have a *proper motion*, that is, a motion exclusively belonging to each individual star, in which the stars around it do not participate. Now, some of the double stars have such a motion. If one individual of the pair were affected by a proper motion, in which the other does not participate, their separation at some subsequent epoch would become inevitable, since one would necessarily move away from the other. Now, no such separation has in any instance been witnessed. It follows, therefore, that the proper motion of one equally affects the other, and consequently, that their juxta-position is real and not merely optical.

52. The systematic observation of double stars, and their reduction to a catalogue with individual descriptions, commenced by Sir W. Herschel, has been continued with great activity and success by Sir J. Herschel, Sir J. South, and Professor Struve, so that the number of these objects now known, as to character and position, amounts to several thousand, the individuals of each pair being less than 32" asunder. They have been classed by Professor Struve according to their distances asunder, the first class being separated by a distance not exceeding 1", the second between 1" and 2", the third between 2" and 4", the fourth between 4" and 8", the fifth between 8" and 12", the sixth between 12" and 16", the seventh between 16" and 24", and the eighth between 24" and 32".

53. The double stars in the following table have been selected

by Sir J. Herschel from Struve's catalogue, as remarkable examples of each class well adapted for observation by amateurs, who may be disposed to try by them the efficiency of telescopes.

0″ to 1″.	1″ to 2″.	2″ to 4″.	4″ to 8″.
γ Coronæ Bor.	γ Circini.	α Piscium.	α Crucis.
γ Centauri.	δ Cygni.	β Hydræ.	α Herculis.
γ Lupi.	ε Chamaleontis.	γ Ceti.	α Gemin.
ε Arietis.	ζ Bootis.	γ Leonis.	δ Gemin.
ζ Herculis.	ι Cassiopeiæ.	γ Cor. Aus.	ζ Cor. Bor.
η Coronæ.	ι 2 Cancri.	γ Virginis.	θ Phænicis.
η Herculis.	ξ Ursæ maj.	δ Serpentis.	κ Cephei.
λ Cassiopeiæ.	π Aquilæ.	ε Bootis.	λ Orionis.
λ Ophiuchi.	σ Coro. Bor.	ε Draconis.	μ Cygni.
π Lupi.	2 Camelopar.	ε Hydræ.	ξ Bootis.
η Ophiuchi.	32 Orionis.	ζ Aquarii.	ξ Cephei.
φ Draconis.	52 Orionis.	ζ Orionis.	π Bootis.
φ Ursæ maj.		ι Leonis.	ρ Capricor.
χ Aquilæ.		ι Trianguli.	ν Argus.
ω Leonis.		κ Leporis.	ω Aurigæ.
Atlas Pleiad.		μ Draconis.	μ Eridani.
4 Aquarii.		μ Canis.	70 Ophiuchi.
42 Comæ.		ρ Herculis.	12 Eridani.
52 Arietis.		σ Cassiopeiæ.	32 Eridani.
66 Piscium.		44 Bootis.	44 Herculis.

8″ to 12″.	12″ to 16″.	16″ to 24″.	21″ to 32″.
β Orionis.	α Centauri.	α Can. Ven.	δ Herculis.
γ Arietis.	β Cephei.	ε Normæ.	η Lyræ.
γ Delphini.	β Scorpii.	ζ Piscium.	ι Cancri.
ζ Antliæ Pn.	γ Volantis.	θ Serpentis.	κ Herculis.
η Cassiopeiæ.	η Lupi.	κ Cor. Aus.	κ Cephei.
θ Eridani.	ζ Ursa maj.	κ Tauri.	ψ Draconis.
ι Orionis.	κ Bootis.	24 Comæ.	κ Cygni.
f Eridani.	8 Monocerotis.	41 Draconis.	23 Orionis.
2 Can. Ven.	61 Cygni.	61 Ophiuchi.	

54. One of the characters observed among the double stars is the frequent occurrence of stars of different colours found together. Sometimes these colours are complementary; and when this occurs, it is possible that the fainter of the two may be a white star, which appears to have the colour complementary to that of the more brilliant, in consequence of a well-understood law of vision, by which the retina being highly excited by light of a particular colour is rendered insensible to less intense light of the same

colour, so that the complement of the whole light of the fainter star finds the retina more sensible than that part which is identical in colour with the brighter star, and the impression of the complementary colour accordingly prevails. In many cases, however, the difference of colour of the two stars is real.

When the colours are complementary, the more brilliant star is generally of a bright red or orange colour, the smaller appearing blueish or greenish. The double stars ι Cancri and γ Andromachæ are examples of this. According to Sir J. Herschel, insulated stars of a red colour, some almost blood-red, occur in many parts of the heavens; but no example has been met with of a decidedly green or blue star unassociated with a much brighter companion.

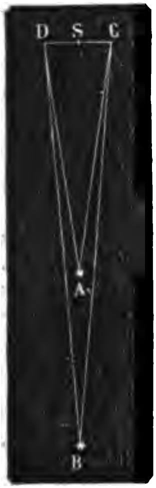
55. When telescopes of the greatest efficiency are directed upon some stars, which to more ordinary instruments appear only double, they prove to consist of three or more stars. In some cases one of the two companions only is double, so that the entire combination is triple. In others, both are double, the whole being, therefore, a quadruple star. An example of this latter class is presented by the star ε Lyræ. Sometimes the third star is much smaller than the principal ones, for example, in the cases of ζ Cancri, ξ Scorpii, 11 Monocerotis, and 12 Lyncis. In others, as in θ Orionis, the four component stars are all conspicuous.

56. When the attention of astronomers was first attracted to double stars, it was thought they would afford a most promising means of determining the annual parallax, and thereby discovering the distance of the stars. If we suppose the two individuals composing a double star, being situate very nearly in the same direction as seen from the earth, to be at very different distances, it might be expected that their apparent relative position would vary at different seasons of the year, by reason of the change of position of the earth.

Let A and B, fig. 6, represent the two individuals composing a double star. Let C and D represent two positions of the earth in its annual orbit, separated by an interval of half a year, and placed therefore on opposite sides of the sun S. When viewed from C, the star B will be to the left of the star A; and when viewed from D, it will be to the right of it. During the intermediate six months the relative change of position would gradually be effected; and the one star would thus appear either to revolve annually round the other, or would oscillate semi-annually from side to side of the other. The extent of its play compared with the diameter C D of the earth's orbit, would supply the data necessary to determine the proportion which the distance of the stars would bear to that diameter.

The great problem of the stellar parallax seemed thus to be reduced to the measurement of the small interval between the individuals of double stars; and it happened fortunately, that the micrometers used in astronomical instruments were capable of measuring these minute angles with much greater relative accuracy than could be attained in the observations on greater angular distances. To these advantages were added the absence of all possible errors arising from refraction, errors incidental to the graduation of instruments, from uncertainty of levels and plumb-lines, from all estimations of aberration and precession; in a word from all effects which, equally affecting both the individual stars observed, could not interfere with the results of the observations, whatever they might be.

Fig. 6.



57. These considerations raised great hopes among astronomers, that the means were in their hands to resolve finally the great problem of the stellar parallax, and Sir William Herschel accordingly engaged, with all his characteristic ardour and sagacity, in an extensive series of observations on the numerous double stars, for the original discovery of which science was already so deeply indebted to his labours. He had not, however, proceeded far in his researches, when phenomena unfolded themselves before him, indicating a discovery of a much higher order and interest than that of the parallax which he sought. He found that the relative position of the individuals of many of the double stars which he examined were subject to a change, but that the period of this change had no relation to the period of the earth's motion. It is evident that whatever appearances can proceed from the earth's annual motion, must be not only periodic and regular, but must pass annually through the same series of phases, always showing the same phase on each return of the same epoch of the sidereal year. In the changes of position which Sir William Herschel observed in the double stars, no such series of phases presented themselves. Periods, it is true, were soon developed; but these periods were regulated by intervals which neither agreed with each other nor with the earth's annual motion.

Fig. 56.*

OVAL BLUISH NEBULA, OBSERVED BY SIR JOHN HERSCHEL.

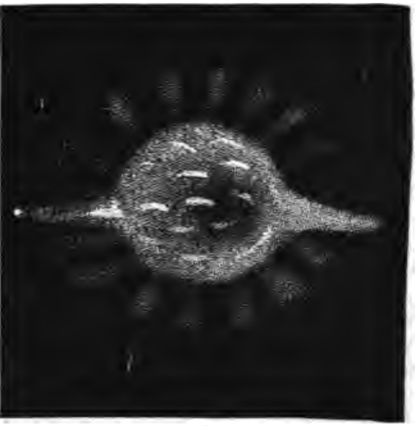


Fig. 57.*

THE SAME OBJECT, AS SHOWN BY THE GREAT ROSSE TELESCOPE.

THE STELLAR UNIVERSE.

CHAPTER IV.

58. His discovery of binary stars.—59. Gravitation of the stars.—60. Star moving round star.—61. Table of binary stars.—62. Case of γ Virginis.—63. System revolving round system. PROPER MOTION OF STARS: 64. The sun not a fixed centre.—65. Phenomena indicating its motion.—66. Direction of the sun's motion.—67. Its velocity.—68. Its probable centre. THE FORM AND DIMENSIONS OF THE MASS OF STARS WHICH COMPOSE THE FIRMAMENT: 69. Distribution of the stars on the firmament.—70. Galactic circle and poles.—71. Variation of stellar density.—72. Struve's analysis of Herschel's observations.—73. The milky way.—74. It consists of innumerable stars crowded together.—75. Probable form of the stratum of stars in which the sun is placed.

58. SOME other explanation of the phenomena must, therefore, be sought for; and the illustrious observer soon arrived at the conclusion, that these apparent changes of position were due to real motions in the stars themselves; that these stars, in fact, moved in proper orbits in the same manner as the planets moved around the sun. The slowness of the succession of changes which

---

* See note, p. 193, vol. vii.

were observed, rendered it necessary to watch their progress for a long period of time before their motions could be certainly or accurately known; and accordingly, although these researches were commenced in 1778, it was not until the year 1803 that the observer had collected data sufficient to justify any positive conclusion respecting their orbital motions. In that and the following year, Sir William Herschel announced to the Royal Society, in two memorable papers read before that body, that there exist sidereal systems consisting of two stars revolving about each other in regular orbits, and constituting what he called *binary stars*, to distinguish them from double stars, generally so called, in which no such periodic change of position is discoverable. Both the individuals of a binary star are at the same distance from the eye in the same sense in which the planet Uranus and its attendant satellites are said to be at the same distance.

More recent observation has fully confirmed these remarkable discoveries. In 1841, Mädler published a catalogue of upwards of 100 stars of this class, and every year augments their number. These stars require the best telescopes for their observation, being generally so close as to render the use of very high magnifying powers indispensable.

59. The moment the revolution of one star round another was ascertained, the idea of the possible extension of the great principle of gravitation to these remote regions of the universe naturally suggested itself. Newton has proved in his *Principia*, that if a body revolve in an ellipse by an attractive force directed to the focus, that force will vary according to the law which characterises gravitation. Thus an elliptical orbit became a *test* of the presence and sway of the law of gravitation. If, then, it could be ascertained that the orbits of the double stars were ellipses, we should at once arrive at the fact that the law of which the discovery conferred such celebrity on the name of Newton, is not confined to the solar system, but prevails throughout the universe.

60. The first distinct system of calculation by which the true elliptic elements of the orbit of a binary star were ascertained, was supplied in 1830, by M. Savary, who showed that the motion of one of the most remarkable of these stars (ξ *Ursæ majoris*), indicated an elliptic orbit described in 58¼ years. Professor Enckė, by another process, arrived at the fact that the star 60 *Ophiuchi* moved in an ellipse with a period of 74 years. Several other orbits were ascertained and computed by Sir John Herschel, MM. Mädler, Hind, Smyth, and others.

61. The following Table is given by Sir J. Herschel, as containing the principal results of observation in this part of stellar astronomy up to 1850.

BINARY STARS.

Star's Name.	Apparent semi-axis.	Excentricity.	Position of Node.	Perihelion from Node of Orbit.	Inclination.	Period in Years.	Perihelion Passage.	By whom computed.
1. Herculis	1·189″	0·44454	39° 26′	262° 4′	50° 53′	31·468	1829·50	Mädler.
2. η Coronæ B.	1·088	0·33760	24 18	261 21	71 8	43·246	1815·23	Ditto.
3. ζ Cancri	1·292	0·23486	1 28	266 0	63 17	58·910	1853·37	Ditto.
4. a. ξ Ursæ majoris	3·857	0·41640	95 22	131 38	50 40	58·262	1817·25	Savary.
4. b. Ditto	3·278	0·37770	97 47	134 22	56 6	60·720	1816·73	Herschel, junior.
4. c. Ditto	2·417	0·41350	98 52	130 48	54 56	61·464	1816·44	Mädler.
5. ω Leonis	0·857	0·64338	135 11	185 27	46 33	82·533	1849·76	Ditto.
6. a. p. Ophiuchi	4·328	0·43007	147 12	125 22	46 25	73·862	1806·88	Encké.
6. b. Ditto	4·392	0·46670	137 2	145 46	48 5	80·340	1807·06	Herschel, junior.
6. c. Ditto	4·192	0·44380	126 55	142 53	64 51	92·870	1812·73	Mädler.
7. Σ 3062	1·255	0·44958	15 3	137 27	35 31	94·765	1837·41	Ditto.
8. ξ Bootis	12·560	0·59374	359 59	100 59	80 5	117·140	1779·88	Herschel, junior.
9. δ Cygni	1·811	0·60667	24 54	243 24	46 23	178·700	1862·87	Hind.
10. γ Virginis	3·580	0·87952	5 33	313 45	23 36	182·120	1836·43	Herschel, junior.
11. a. Castor	8·086	0·75820	58 6	97 29	70 3	252·660	1855·83	Ditto.
11. b. Ditto	7·008	0·79725	23 5	87 37	70 58	232·124	1913·90	Mädler.
11. c. Ditto	6·300	0·24050	11 24	356 22	43 14	632·270	1699·26	Hind.
12. a. σ Coronæ B.	3·918	0·69978	25 7	64 38	29 29	608·450	1826·60	Mädler.
12. b. Ditto	5·194	0·72560	21 3	69 24	25 39	736·880	1826·48	Hind.
13. μ 2 Bootis	3·218	0·84010	117 21	103 17	46 57	649·720	1852·50	Ditto.
14. α Centauri	15·500	0·95000	86 7	291 22	47 56	77·000	1851·50	Jacob.

The elements Nos. 1, 2, 3, 4 c, 5, 6 c, 7, 11 b, 12 a, are extracted from M. Mädler's synoptic view of the history of double stars, in vol. ix. of the Dorpat Observations: 4 a, from the Connoiss. des Temps, 1830: 4 b, 6 b, and 11 a, from vol. v. Trans. Astron. Soc. Lond.: 6 a, from Berlin Ephemeris, 1832: No. 8. from Trans. Astron. Soc. vol. vi.: No. 9, 11 c, 12 b, and 13 from Notices of the Astronomical Society, vol. vii. p. 22., and viii. p. 159., and No. 10 from Sir John Herschel's "Results of Astronomical Observations, &c., at the Cape of Good Hope," p. 297. The Σ prefixed to No. 7 denotes the number of the star in M. Struve's Dorpat Catalogue (Catalogus Novus Stellarum Duplicium, &c., Dorpat. 1827), which contains the places for 1826 of 3112 of these objects.

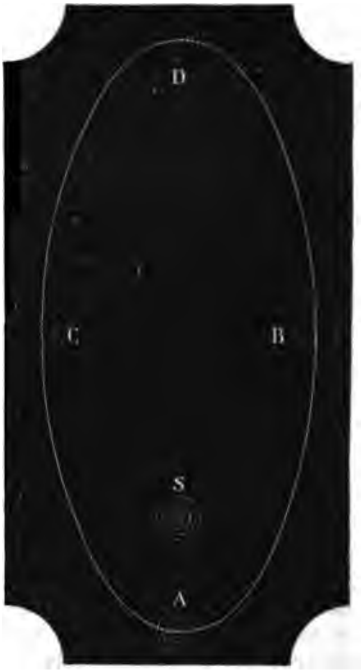
The "position of the node" in col. 4, expresses the angle of position of the line of intersection of the plane of the orbit, with the plane of the heavens on which it is seen projected. The "inclination" in col. 6, is the inclination of these two planes to one another. Col. 5, shows the angle actually included *in the plane of the orbit*, between the line of nodes (defined as above) and the line of apsides. The elements assigned in this table to ω Leonis, ξ Bootis, and Castor must be considered as very doubtful, and the same may perhaps be said of those ascribed to μ 2 Bootis, which rest on too small an arc of the orbit, and that too imperfectly observed, to afford a secure basis of calculation.

62. The most remarkable of these, according to Sir John Herschel, is γ *Virginis;* not only on account of the length of its period, but by reason also of the great diminution of apparent distance and rapid increase of angular motion about each other, of the individuals composing it. It is a bright star of the fourth magnitude, and its component stars are almost exactly equal. It has been known to consist of two stars since the beginning of the eighteenth century, their distance being then between six and seven seconds; so that any tolerably good telescope would resolve it. Since that time they have been constantly approaching, and are at present hardly more than a single second asunder; so that no telescope that is not of very superior quality, is competent to show them otherwise than as a single star somewhat lengthened in one direction. It fortunately happens that Bradley, in 1718, noticed and recorded, in the margin of one of his observation-books, the apparent direction of their line of junction as being parallel to that of two remarkable stars α and δ of the same constellation, as seen by the naked eye. They are entered also as distinct stars in Mayer's catalogue; and this affords also another means of recovering their relative situation at the date of his observations, which were made about the year 1756. Without particularising individual measurements, which will be found in their proper repositories, it will suffice to remark, that their whole series is represented by an ellipse.

63. To understand the curious effects which must attend the case of a lesser sun with its attendant planets revolving round a

greater, let the larger sun with its planets be represented at S, fig. 7, in the focus of an ellipse, in which the lesser sun accompanied by *its* planets moves. At A this latter sun is in its perihelion, and nearest to the greater sun S. Moving in its periodical course to B, it is at its mean distance from the sun S. At D it is at aphelion, or its most distant point, and finally returns through C to its perihelion A. The sun S, because of its vast distance from the system A, would appear to the inhabitants of the planets of the system A much smaller than their proper sun; but, on the other hand, this effect of distance would be to a certain extent compensated by its greatly superior magnitude; for analogy justifies the inference that the sun S is greater than the sun A in a proportion equal to that of the magnitude of our sun to one of the planets. The inhabitants of the planets of the system A will then behold the spectacle of *two suns* in their firmament. The annual motion of one of these suns will be determined by the motion of the planet itself in its orbit, but that of the other and more distant sun will be determined by the period of the lesser sun around the greater in the orbit A B D C. The rotation of the planets on their axes will produce two days of equal length, but not commencing or ending simultaneously. There will be in general *two sunrises* and *two sunsets!* When a planet is situate in the part of its orbit between the two suns, there will be no night. The two suns will then be placed exactly as our sun and moon are placed when the moon is full. When the one sun sets, the other will rise; and when the one rises the other will set. There will be, therefore, continual day. On the other hand, when a planet is at such a part of its orbit that both suns lie in nearly the same direction as seen from it, both suns will rise and both will set together. There

Fig. 7.



will then be the ordinary alternation of day and night as on the earth, but the day will have more than the usual splendour, being enlightened by two suns.

In all intermediate seasons the two suns will rise and set at different times. During a part of the day both will be seen at once in the heavens, occupying different places, and reaching the meridian at different times. There will be *two noons*. In the morning for some time, more or less, according to the season of the year, one sun only will be apparent, and in like manner, in the evening, the sun which first rose will be the first to set, leaving the dominion of the heavens to its splendid companion.

The diurnal and annual phenomena incidental to the planets attending the central sun s will not be materially different, except that to them the two suns will have extremely different magnitudes, and will afford proportionally different degrees of light. The lesser sun will appear much smaller, both on account of its really inferior magnitude, and its vastly greater distance. The two days, therefore, when they occur, will be of very different splendour, one being probably as much brighter than the other as the light of noonday is to that of full moonlight, or to that of the morning or evening twilight.

But these singular vicissitudes of light will become still more striking, when the two suns diffuse light of different colours. Let us examine the very common case of the combination of a *crimson* with a *blue* sun. In general, they will rise at different times. When the blue rises, it will for a time preside alone in the heavens, diffusing a blue morning. Its crimson companion, however, soon appearing, the lights of both being blended, a white day will follow. As evening approaches, and the two orbs descend toward the western horizon, the blue sun will first set, leaving the crimson one alone in the heavens. Thus a ruddy evening closes this curious succession of varying lights. As the year rolls on, these changes will be varied in every conceivable manner. At those seasons when the suns are on opposite sides of a planet, crimson and blue days will alternate, without any intervening night; and at the intermediate epochs all the various intervals of rising and setting of the two suns will be exhibited.

PROPER MOTION OF THE STARS.

In common parlance the stars are said to be *fixed*. They have received this epithet to distinguish them from the planets, the sun, and the moon, all of which constantly undergo changes of apparent position on the surface of the heavens. The stars, on the contrary, so far as the powers of the eye unaided by art can discover, never change their relative position in the firmament, which seems to be carried round us by the diurnal motion of the sphere, just as if the stars were attached to it, and merely shared in its apparent motion.

But the stars, though subject to no motion perceptible to the naked eye, are not absolutely fixed. When the place of a star on the heavens is exactly observed by means of good astronomical instruments, it is found to be subject to a change from month to month and from year to year, small indeed, but still easily observed and certainly ascertained.

64. It has been demonstrated by Laplace, that a system of bodies, such as the solar system, placed in space and submitted to no other continued force except the reciprocal attractions of the bodies which compose it, must either have its common centre of gravity stationary or in a state of uniform rectilinear motion.

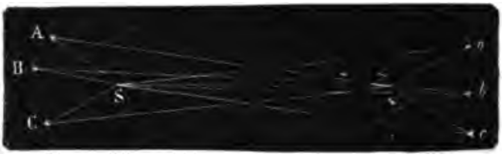
The chances against the conditions which would render the sun stationary, compared with those which would give it a motion in *some* direction with *some* velocity, are so numerous that we may pronounce it to be morally certain that our system is in motion in some determinate direction through the universe. Now, if we suppose the sun attended by the planets to be thus moved through space in any direction, an observer placed on the earth would see the effects of such a motion, as a spectator in a steamboat moving on a river would perceive his progressive motion on the stream by an apparent motion of the banks in a contrary direction. The observer on the earth would, therefore, detect such a motion of the solar system through space by the apparent motion in the contrary direction with which the stars would be affected.

65. Such a motion of the solar system would affect different stars differently. All would, it is true, appear to be affected by a contrary motion, but all would not be equally affected. The nearest would appear to have the most perceptible motion, the more remote would be affected in a less degree, and some might, from their extreme distance, be so slightly affected as not to exhibit any apparent change of place, even when examined with the most delicate instruments. To whatever degree each star might be affected, all the changes of position would, however, apparently take place in the same direction.

The apparent effects would also be exhibited in another manner. The stars in that region of the universe toward which the motion of the system is directed, would appear to recede from each other. The spaces which separate them would seem to be gradually augmented, while, on the contrary, the stars in the opposite quarter would seem to be crowded more closely together, the distances between star and star being gradually diminished. This will be more clearly comprehended by fig. 8.

Let the line S S′ represent the direction of the motion of the system, and let S and S′ represent its positions at any two epochs. At S, the stars A B C would be separated by intervals measured by the angles A S B, and B S C, while at S′ they would appear separated by the lesser angles A S′ B, and B S′ C. Seen from S′, the stars A B C would seem to be closer together than they were when seen from S. For like reasons, the stars *a b c*, towards which the system is here supposed to move, would seem to be closer together when seen from S, than when seen from S′. Thus, in the quarter of the heavens towards which the system is moving, the stars might be expected to separate gradually, while in the opposite quarter they would become more condensed. In all the intermediate parts of the heavens they would be affected by a motion contrary to that of the solar system. Such, in general, would be the effects of a progressive motion of our system.

Fig. 8.



66. Although no general effect of this kind has been manifested in any conspicuous manner among the fixed stars, many of these objects have been found, in long periods of time, to have shifted their position in a very sensible degree. Thus, for example, the three stars, Sirius, Arcturus, and Aldebaran, have undergone, since the time of Hipparchus (130 B.C), a change of position southwards, amounting to considerably more than half a degree. The double star 61 Cygni has, in half a century, moved through nearly 4·3′, the two stars composing it being carried along in parallel lines with a common velocity. The stars ε Indi and μ Cassiopeiæ move at the rate of 7·74″ and 3·74″ annually.

Various attempts have been made to render these and other like changes of apparent position of the fixed stars compatible with some assumed motion of the sun. Sir W. Herschel, in 1783, reasoning upon the proper motions which had then been observed, arrived at the conclusion, that such appearances might be explained by supposing that the sun has a motion directed to a point near the star λ Herculis. About the same time, Prevost came to a like conclusion, assigning, however, the direction of the supposed motion to a point differing by 27° from that indicated by Sir W. Herschel.

Since that epoch, the proper motions of the stars have been more extensively and accurately observed, and calculations of the motions of the sun which they indicate, have been made by several astronomers. The following points have been assigned as the direction of the solar motion in 1790:—

R. A.	N. P. D.	
260° 34′	63° 43′	Sir W. Herschel.
256° 25′	51° 23′	Argelander.
255° 10′	51° 26′	,,
261° 11′	59° 2′	,,
252° 53′	75° 34′	Luhndahl.
261° 22′	62° 24′	Otto Struve.

The first estimate of Argelander was made from the proper motions of 21 stars, each of which has an annual motion greater than 1″; the second from 50 stars having annual proper motions between 1″ and 0·5″, and the third from those of 319 stars having motions between 0·5″ and 0·1″. The estimate of M. Luhndahl is based on the motions of 147 stars, and that of M. Struve on 392 stars.

The mean of all these estimates * is a point whose right ascension is 259° 9′, and north polar distance 55° 23′, which it will be seen differs very little from the point originally assigned by Sir W. Herschel.

All the preceding calculations being based on observations made on stars in the northern hemisphere, it was obviously desirable that similar estimates should be made from the observed proper motions of southern stars. Mr. Galloway undertook and executed these calculations; and found that the southern stars gave the direction of the solar motion for 1790, to be towards a point whose right ascension is 260° 1′, and north polar distance 55° 37′.

No doubt, therefore, can remain that the proper motion of the stars is produced by a real motion of the solar system, and that the direction of this motion in 1790 was towards a point of space which seen from the then position of the system had the right ascension of about 260°, and the north polar distance of about 55°.

67. It follows from these calculations, that the average displacement of the stars requires that the motion of the sun should be such as that if its direction were at right angles to a visual ray, drawn from a star of the first magnitude of average distance, its apparent annual motion would be 0·3392″; and taking the average parallax of such a star at 0·209″, if D express the semi-axis of the earth's orbit, the annual motion of the sun would be

$$\frac{3392}{2090} \times \text{D} = 1{\cdot}623 \text{ D}.$$

---

* Herschel, Ast., 2nd Ed., p. 583.

It follows therefore, that the annual motion of the sun would be

$$1{\cdot}623 \times 95{,}000000 = 154{,}200000 \text{ miles};$$

and the daily motion

$$\frac{154{,}200000}{365\frac{1}{4}} = 422000 \text{ miles};$$

a velocity equal to something more than the fourth of the earth's orbital motion.

68. The motion of the sun, which has been computed in what precedes, is that which it had at a particular epoch. No account is taken of the possible or probable changes of direction of such motion. To suppose that the solar system should move continuously in one and the same direction, would be equivalent to the supposition that no body or collection of bodies in the universe would exercise any attraction upon it. It is obviously more consistent with probability and analogy, that the motion of the system is *orbital*, that is to say, that it revolves round some remote centre of attraction, and that the direction of its motion must continually change, although such change, owing to the great magnitude of its orbit, and the relative slowness of its motion, be so very slow as to be quite imperceptible within even the longest interval over which astronomical records extend.

Attempts have, nevertheless, been made to determine the centre of the solar motion; and Dr. Mädler has thrown out a surmise that it lies at a point in or near the small constellation of the Pleiades.

This and like speculations must, however, be regarded as conjectural for the present.

THE FORM AND DIMENSIONS OF THE MASS OF STARS WHICH COMPOSE THE VISIBLE FIRMAMENT.

69. The aspect of the firmament might, at first, impress the mind of an observer with the idea that the numerous stars scattered over it are destitute of any law or regularity of arrangement, and that their distribution is like the fortuitous position which objects casually flung upon such a surface might be imagined to assume. If, however, the different regions of the heavens be more carefully examined and compared, this first impression will be corrected, and it will, on the contrary, be found that the distribution of the stars over the surface of the celestial sphere follows a distinct and well defined law; that their density, or the number of them which is found in a given space of the heavens, varies regularly, increasing continually in certain directions and decreasing in others.

Sir W. Herschel submitted the heavens, or at least that part of them which is observable in these latitudes, to a rigorous telescopic survey, counting the number of individual stars visible in the field of view of a telescope of given aperture, focal length, and magnifying power, when directed to different parts of the firmament. The result of this survey proved that, around two points of the celestial sphere diametrically opposed to each other, the stars are more thinly scattered than elsewhere; that departing from these points in any direction, the number of stars included in the field of view of the same telescope increases first slowly, but at greater distances more rapidly; that this increase continues until the telescope receives a direction at right angles to the diameter which joins the two opposite points where the distribution is most sparse; and that in this direction the stars are so closely crowded together that it becomes, in some cases, impracticable to count them.

70. The two opposite points of the celestial sphere, around which the stars are observed to be most sparse, have been called the GALACTIC POLES; and the great circle at right angles to the diameter joining these points, has been denominated the GALACTIC CIRCLE.

This circle intersects the celestial equator at two points, situate 10° east of the equinoctial points, and is inclined to the equator at an angle of 63°, and, therefore, to the ecliptic at an angle of 40°.

In referring to and explaining the distribution of the stars over the celestial sphere, it will be convenient to refer them to this circle and its poles, as, for other purposes, they have been referred to the equator and its poles. We shall, therefore, express the distance of different points of the firmament from the galactic circle, in either hemisphere, by the terms north or south GALACTIC LATITUDE.

71. The elaborate series of stellar observations in the northern hemisphere made during a great part of his life, by Sir W. Herschel, and subsequently extended and continued in the southern hemisphere by Sir J. Herschel, has supplied data by which the law of the distribution of the stars, according to their galactic latitude, has been ascertained at least with a near approximation.

The great celestial survey executed by these eminent observers, was conducted upon the principle explained above. The telescope used for the purpose had 18 inches aperture, 20 feet focal length, and a magnifying power of 180. It was directed indiscriminately to every point of the celestial sphere visible in the latitude of the places of observation.

It was by means of a vast number of distinct observations thus made, that the position of the galactic poles was ascertained. The density of the stars, measured by the number included in each "gauge" (as the field of view was called), was nearly the same for the same galactic latitude, and increased in proceeding from the galactic pole, very slowly at first, but with great rapidity when the galactic latitude was much diminished.

72. An analysis of the observations of Sir W. Herschel, in the northern hemisphere, was made by Professor Struve, with the view of determining the mean density of the stars in successive zones of galactic latitude; and a like analysis has been made of the observations of Sir J. Herschel, in the southern hemisphere.

If we imagine the celestial sphere resolved into a succession of zones, each measuring 15° in breadth, and bounded by parallels to the galactic circle, the average number of stars included within a circle, whose diameter is 15′, and whose magnitude, therefore, would be about the fourth part of that of the disc of the sun or moon, will be that which is given in the second column of the following Table.

Galactic Latitude.	Average number of Stars in a circle 15′ diameter.
N 90° — 75°	4·32
,, 75° — 60°	5·42
,, 60° — 45°	8·21
,, 45° — 30°	13·61
,, 30° — 15°	24·09
,, 15° — 0°	53·43
S 0° — 15°	52·06
,, 15° — 30°	26·29
,, 30° — 45°	13·49
,, 45° — 60°	9·08
,, 60° — 75°	6·62
,, 75° — 90°	6·05

It appears, therefore, that the variation of the density of the visible stars in proceeding from the galactic plane, either north or south, is subject almost exactly to the same law of decrease, the density, however, at each latitude being somewhat greater in the southern than in the northern hemisphere.

73. The regions of the heavens, which extend to a certain distance on one side and the other of the galactic plane, are generally so densely covered with small stars, as to present to the naked eye the appearance, not of stars crowded together, but of whitish nebulous light. This appearance extends over a vast extent of the celestial sphere, deviating in some places from the exact direction of the galactic circle, bifurcating and diverging into two branches at a certain point which afterwards reunite, and at other places throwing out off-shoots. This appearance was denominated the *Via Lactea*, or the *galaxy*,* by the ancients, and it has retained that name.

The course of the milky way may be so much more easily and clearly followed by means of a map of the stars, or a celestial globe, upon which it is delineated, that it will be needless here to describe it.

---

* From the Greek word γάλα, γάλακτος, "milk."

74. When this nebulous whiteness is submitted to telescopic examination with instruments of adequate power, it proves to be a mass of countless numbers of stars, so small as to be individually undistinguishable, and so crowded together as to give to the place they occupy the whitish appearance from which the milky way takes its name.

Some idea may be formed of the enormous number of stars which are crowded together in those parts of the heavens, by the actual numbers so distinctly visible as to admit of being counted or estimated, which are stated by Sir W. Herschel to have been seen in spaces of given extent. He states, for example, that in those parts of the milky way in which the stars were most thinly scattered, he sometimes saw eighty stars in each field. In an hour, fifteen degrees of the firmament were carried before his telescope, showing successively sixty distinct fields. Allowing eighty stars for each of these fields, there were thus exhibited, in a single hour, without moving the telescope, four thousand eight hundred distinct stars! But by moving the instrument at the same time in the vertical direction, he found that in a space of the firmament, not more than fifteen degrees long, by four broad, he saw fifty thousand stars, large enough to be individually visible and distinctly counted! The surprising character of this result will be more adequately appreciated, if it is remembered that this number of stars thus seen in the space of the heavens, not more than thirty diameters of the moon's disc in length, and eight in breadth, is fifty times greater than all the stars taken together, which the naked eye can perceive at any one time in the heavens, on the most serene and unclouded night!

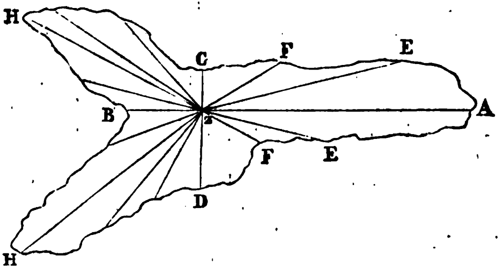
On presenting the telescope to the richer portion of the *via lactea*, Herschel found, as might be expected, much greater numbers of stars. In a single field he was able to count 588 stars; and for fifteen minutes, the firmament being moved before his telescope by the diurnal motion, no diminution of number was apparent; the number seen at any one time being greater than can be seen by the naked eye, on the entire firmament, except on the clearest nights.

75. It may be considered as established by a body of analogical evidence, having all the force of demonstration, that the fixed stars are self-luminous bodies, similar to our sun; and that although they may differ more or less from our sun and from each other in magnitude and intrinsic lustre, they have a certain average magnitude; and that, therefore, in the main, the great

differences which are apparent in their brightness, is to be ascribed to difference of distance. Assuming, then, that they are separated from each other by distances analogous to their distances from the sun, itself a star, the general phenomena which have been described above, involving the rapid increase of stellar density in approaching the galactic plane, combined with the observed form of the milky way, which, following the galactic plane in its general course, departs nevertheless from it at some points, bifurcates resolving itself into two diverging branches at others, and at others throws out irregular off-shoots, conducted Sir W. Herschel to the conclusion, that the stars of our firmament, including those which the telescope renders visible, as well as those visible to the naked eye, instead of being scattered indifferently in all directions around the solar system through the depths of the universe, form a stratum of definite form and dimensions, of which the thickness bears a very small proportion to the length and breadth, and that the sun and solar system is placed within this stratum, very near its point of bifurcation, relatively to its breadth near its middle point, and relatively to its thickness (as would appear from the more recent observations) nearer to its northern than to its southern surface.

Let A C H D, fig. 9, represent a rough outline of a section of such a stratum, made by a plane passing through or near its centre.

Fig. 9.



Let A B represent the intersection of this with the plane of the galactic circle, so that, z being the place of the solar system, z C will be the direction of the north, and z D that of the south galactic pole. Let z H represent the two branches which bifurcate from the chief stratum at B. Now, if we imagine visual lines to be drawn from z in all directions, it will be apparent that those z C and z D, which are directed to the galactic poles, pass through a thinner bed of stars than any of the others; and since z is supposed to be nearer to the northern than to the southern side of the stratum, z C will pass through a less thickness of stars than z D. As the visual lines are inclined at greater and greater angles to z A, their length rapidly decreases, as is evident by comparing z A, z E, and z F, which explains the fact that while the stars are as thick as powder in the direction z A, they become less so in the direction z E, and still less in the direction z F, until at the poles in the directions z C and z D, they become least dense.

On the other side, z B being less than z A, a part of the galactic circle is found at which the stars are more thinly scattered; but in two directions, z H intermediate between z B and the galactic poles, they again become nearly as dense as in the direction z A.

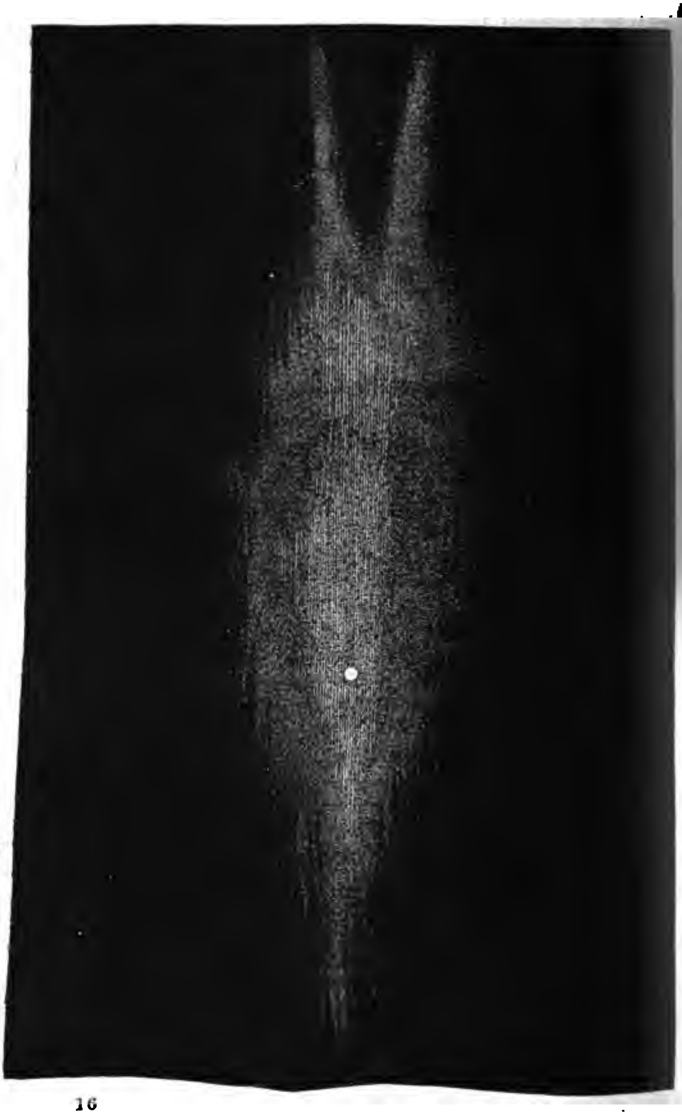
This illustration must, however, be taken in a very general sense. No attempt is made to represent the various off-shoots and variations of length, breadth, and depth of the stratum measured from the position of the solar system within it, which have been indicated by the telescopic *soundings* of Sir W. Herschel and his illustrious son, whose wondrous labours have effected what promises in time, by the persevering researches of their successors, to become a complete analysis of this most marvellous mass of systems. Meanwhile it may be considered as demonstrated, that it consists of myriads of stars clustered together:—

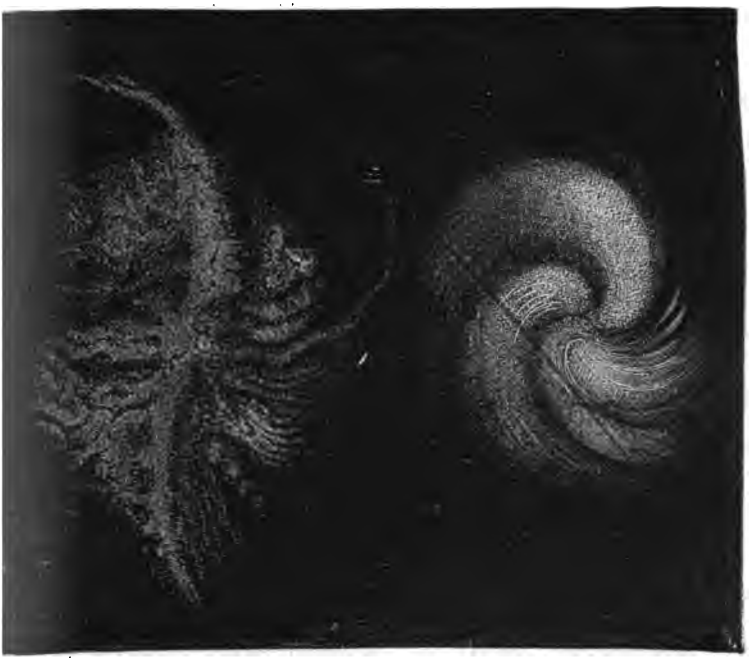
> "A broad and ample road, whose dust is gold,
> And pavement stars, as stars to us appear;
> Seen in the galaxy that Milky Way,
> Like to a circling zone powder'd with stars."—MILTON.

The appearance which this mass of stars would present if viewed from a position directly above its general plane, and at a sufficient distance to allow its entire outline to be discerned, was represented by Sir William Herschel as resembling the starry stratum sketched in fig. 10.

He considered that it was probable that the *thickness* of this *bed of stars* was equal to about eighty times the distance of the nearest of the fixed stars from our system; and supposing our sun to be near the middle of this thickness, it would follow that the stars on its surface in a direction perpendicular to its general plane would be at the fortieth order of distance from us. The stars placed in the more remote edges of its *length* and *breadth* he estimated to be in some places at the nine-hundredth order of distance from us, so that its extreme length may be said to be in round numbers about 2000 times the distance of the nearest fixed stars from our system. Such a space light would take 20000 years to move over, moving all that time at the rate of nearly 200000 miles between every two ticks of a common clock!

Fig. 10.





Figs. 35, 36.—SPIRAL NEBULÆ, AS SHOWN BY THE GREAT ROSSE TELESCOPE.

THE STELLAR UNIVERSE.

CHAPTER V.

STELLAR CLUSTERS AND NEBULÆ: 76. The stars of the firmament a stellar cluster.—77. Such clusters innumerable.—78. Their distribution on the firmament.—79. Their constitution.—80. Their apparent and real forms.—81. Nebulæ.—82. Double nebulæ.—83. Planetary nebulæ.—84. Annular nebulæ.—85. Spiral nebulæ.

STELLAR CLUSTERS AND NEBULÆ.

76. It appears, then, that our sun is an individual star, forming only a single unit in a cluster or mass of many millions of other similar stars; that this cluster has limited dimensions, has ascertainable length, breadth, and thickness, and, in short, forms what may be expressed by a *universe of solar systems*. The mind, still

unsatisfied, is as urgent as before in its questions regarding the *remainder of immensity*. However vast the dimensions of this mass of suns be, they are nevertheless finite. How stupendous soever be the space included within them, it is still *nothing* compared to the immensity which lies outside! Is that immensity a vast solitude? Are its unexplored realms dark and silent? Has Omnipotence circumscribed its agency, and has Infinite Beneficence left those unfathomed regions destitute of evidence of His power?

That the infinitude of space should exist without a purpose, unoccupied by any works of creation, is plainly incompatible with all our notions of the character and attributes of the Author of the universe, whether derived from the voice of revelation or from the light of nature. We should therefore infer, even in the absence of direct evidence, that *some* works of creation are dispersed through those spaces which lie beyond the limits of that vast stellar cluster of which our system is a part. Nay, we should be led, by the most obvious analogies, to conjecture that *other stellar clusters*, like our own, are dispersed through immensity, separated probably by distances as much greater than those which intervene between star and star, as the latter are greater than those which separate the bodies of the solar system. But if such distant clusters existed, it may be objected, that they must be visible to us; that although diminished, perhaps, to mere spots on the firmament, they would still be rendered apparent, were it only as confused whitish patches, by the telescope; that as the stars of the milky way assume to the naked eye the appearance of mere whitish nebulosity, so the far more distant stars of other clusters, which cannot be perceived at all by the naked eye, would, to telescopes of adequate power, present the same whitish nebulous appearance; and that we might look forward without despair to such augmentation of the powers of the telescope as may even enable us to perceive them to be actual clusters of stars.

77. Such anticipations have accordingly been realised. In various parts of the firmament objects are seen which, to the naked eye, appear like stars seen through a mist, and sometimes as nebulous specks, which might be, and not infrequently have been, mistaken for comets. With ordinary telescopes these objects are visible in very considerable numbers, and were observed nearly a century ago. In the *Connaissance des Temps*, for 1784, Messier, then so celebrated for his observations on comets, published a catalogue of 103 objects of this class, of many of which he gave drawings, with which all observers who search for comets ought to be familiar, to avoid being misled by their resemblance to them. The improved powers of the telescope speedily disclosed to astro-

nomers the nature of these objects, which, when examined by sufficient magnifying powers, prove to be masses of stars clustered together in a manner identical with that cluster in which our sun is placed. They appear as they do, mere specks of whitish light, because of their enormous distance.

78. These objects are not dispersed fortuitously and indifferently on all parts of the heavens. They are wholly absent from some regions, in some rarely found, and crowded in amazing profusion in others. Their disposition, however, is not like that of the stars in general, determined by a great circle of the sphere and its poles. It was supposed that they showed a tendency to crowd towards a zone at right angles to the galactic circle, but a careful comparison of their position does not confirm this. According to Sir W. and Sir J. Herschel, the nebulæ prevail most around the following parts of the celestial sphere:—

1 The North Galactic Pole.
2 Leo major.
3 Leo minor.
4 Ursa major.
5 Canes Venatici.
6 Coma Berenici.
7 Bootes (precedingly).
8 Virgo (head, wings, and shoulder).

The parts of the heavens, on the other hand, where they are found in the smallest numbers, are,—

1 Aries.
2 Taurus.
3 Orion (head and shoulders).
4 Auriga.
5 Perseus.
6 Camelopardus.
7 Draco.
8 Hercules.
9 Serpentarius (northern part).
10 Serpens (tail).
11 Aquila (tail).
12 Lyra.

In the southern hemisphere their distribution is more uniform.

79. What those objects are, and of what they severally consist, admits of no reasonable doubt. So far as relates to the stellar clusters, their constituent parts are visible. They are, as their name imports, masses of stars collected together at certain points in the regions of space which stretch beyond the limits of our own cluster, and are by distance so reduced in their visual magnitude, that an entire cluster will appear to the naked eye, if it be visible at all, as a single star, and when seen with the telescope will be included within the limit of a single field of view.

Different clusters exhibit their component stars seen with the same magnifying power more or less distinctly. Thus, for example, fig. 11 represents the appearance of a cluster seen with a powerful telescope, in which the stars appear like grains of silver powder.

In fig. 12, on the other hand, the component stars are distinct, and those of fig. 13 still more so.

This may be explained either by difference of distance, or by the supposition that they may consist of stars of different real magnitudes, and crowded more or less closely together. The former supposition is, however, by far the more natural and probable.

The appearance of the stars composing some of the clusters is quite gorgeous. Sir J. Herschel says, that the cluster which surrounds κ Crucis in the southern hemisphere, occupies the 48th part of a square degree, or about the tenth part of the superficial magnitude of the moon's disc, and consists of about 110 stars from the 7th magnitude downwards, eight of the more conspicuous stars being coloured with various tints of red, green, and blue, so as to give to the whole the appearance of a rich piece of jewellery.

Fig. 11.

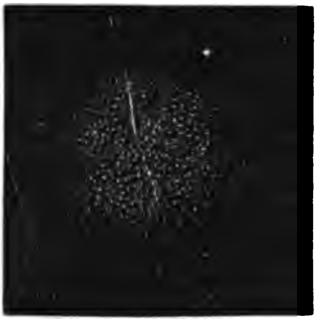
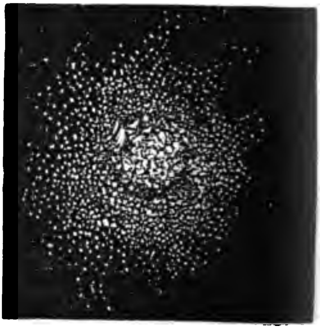
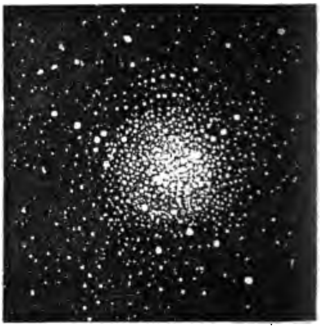


Fig. 12.



Cluster compared with cluster show all gradations of smallness and closeness of the component stars, until they assume the appearance of patches of starry powder. These varieties are more obviously ascribable to varying distances.

Fig. 13.



Then follow those patches of starry light which are seen in so many regions of the heavens, and which have been denominated nebulæ, appearing with very different degrees of magnitude and brightness. Telescopic views of three such are given in figs. 14, 15, and 16.

That these are still clusters, of which the component stars are indistinguishable by reason of their remoteness, there are the strongest evidence and most striking analogies to prove. Every augmentation of power and improvement of efficiency the telescope receives, augments the number of nebulæ which are converted by that instrument into clusters. Nebulæ which were irresolvable before the time of Sir W. Herschel, yielded in large numbers to the powers of the instruments which that observer brought to bear upon them. The labours of Sir J. Herschel, the colossal telescopes constructed by Lord Rosse, and the erection of observatories in multiplied numbers in climates and under skies more favourable to observation, have all tended to augment the number of nebulæ which have been resolved, and it may be expected that this progress will continue, the resolution of these objects into stellar clusters being co-extensive with the improved powers of the telescope and the increased number and zeal of observers.

Fig. 14.

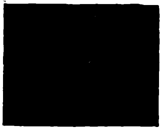


Fig. 15.

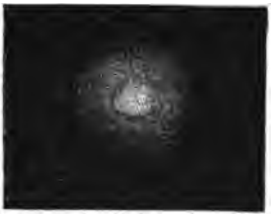
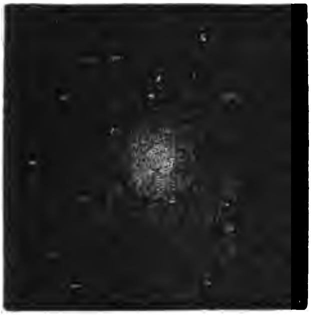


Fig. 16.



A theory was put forward to explain these objects, based upon views not in accordance with what has just been related. It was assumed hypothetically that the nebulous matter was a sort of luminous fluid diffused through different parts of the universe; that by its aggregation on certain laws of attraction, solid luminous masses in process of time were produced, and that these nebulæ grew into clusters.

It would not be compatible with the limits of this Tract, and the objects to which it is directed, to pursue this speculation through its consequences, to state the arguments by which it is supported and opposed; and it is the less necessary to do so, seeing that such an hypothesis is not needed to explain appearances which are so much more obviously and simply explicable by the admission of a gradation of distances.

80. The apparent forms of these objects are extremely various, and subject to most extraordinary and unexpected changes, according to the magnifying power under which they are viewed. This ought, however, to excite no surprise. The telescope is an expedient by which a well-defined and strongly illuminated optical image of a distant object is formed so close to the observer, that he is enabled to view it with microscopes of greater or less power, according to the perfection of its definition, and the intensity of its illumination. Now, it is known to all who are familiar with the use of the microscope, that the apparent form and structure of an object change in the most remarkable and unexpected way when viewed with different microscopic powers. The blood, for example, which viewed with the naked eye, or with low powers, is a uniformly red fluid, appears as a pellucid liquid, having small red discs floating in it, when seen with higher powers. Like effects are manifested in the cases of the nebulæ, when submitted to examination with different and increasing magnifying powers, of which we shall presently show many striking examples.

Stellar clusters are generally roundish or irregular patches. The stars which compose them are always much more densely crowded together, in going from the edges of the cluster towards the centre, so that at the centre they exhibit a perfect blaze of light.

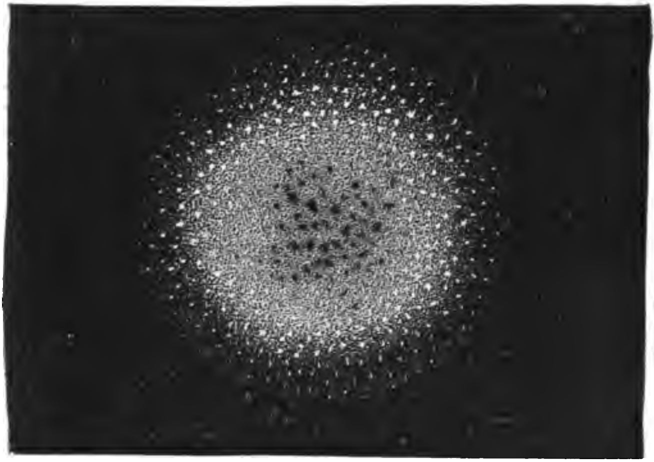
The apparent form is that of a section of the real form, made by a plane at right angles to the visual ray. If the mass had a motion of rotation, or any other motion by which it would change this plane, so as to exhibit to the eye successively different sections of it, its real form could be inferred as those of the planets have been. But there are no discoverable indications of any such motion in these objects. Their real forms, therefore, can only be conjectured from comparing their apparent forms with their structural appearance.

The clusters having round apparent forms, and of which the stars are rapidly more dense towards the centres, are inferred to be either globular or spheroidal masses of stars, the greater apparent density in passing from the edges to the centre being explained by the greater thickness of the mass, in the direction of the visual line. Clusters of irregular outline which show also a density increasing inwards, are also inferred, for like reasons, to be masses of stars, whose dimensions in the direction of the visual rays correspond with their dimensions in the direction at right angles to those rays.

In fig. 17 is represented a cluster observed and delineated by Sir J. Herschel. It is situated at about 1½° south of the celestial equator, and about 38½° east of the autumnal equinoctial point. It occupies a space on the heavens, the diameter of which is equal to the 300th part of that of the full moon. Sir John Herschel, who observed it with a reflecting telescope of nine inch aperture, describes its appearance as that of a most superb cluster of stars of the fifteenth magnitude, so condensed towards the centre as to become a perfect blaze of light. He compares it to a mass of fine luminous sand.

Nothing can be more striking than the different appearances which the same objects have presented, when viewed by the telescopes of Sir John Herschel and the more powerful instruments constructed by the Earl of Rosse. In fig. 18 we have given the same cluster as it appears in one of Lord Rosse's telescopes.

Fig. 17.

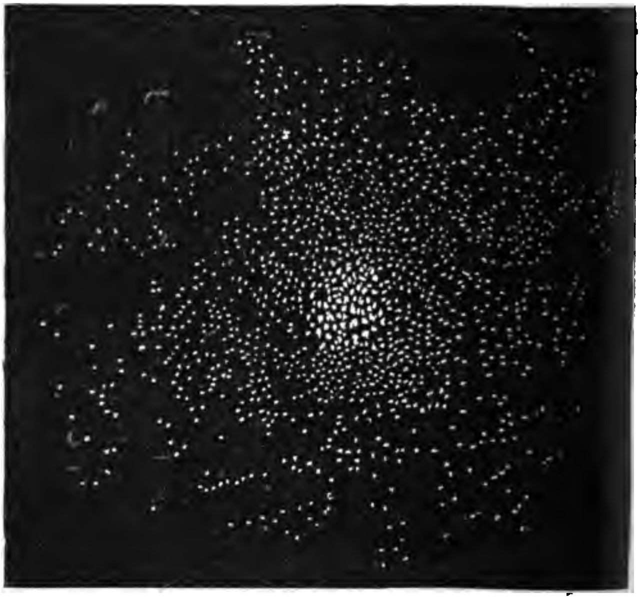


The stars which, in Sir John Herschel's instruments, are crowded together so as to produce a blaze of light, are completely separated by the telescope of Lord Rosse.

In fig. 19 is represented an object as delineated by Sir John Herschel, which appears in his telescope as a fine oval nebula, the length of which is about the eighth, and the breadth the tenth, part of the moon's diameter. This nebula is situated a few degrees north of the constellation of Orion, between it and Aldebaran.

In fig. 20, the same object is delineated as shown by Lord Rosse's telescope. Here a still greater change of appearance is produced than in the former case. The oval form is lost, and converted into that which is shown in the figure. The object is studded with innumerable stars, which are projected upon a nebulous ground. This nebulous ground would most evidently be resolved into stars if viewed with still higher powers.

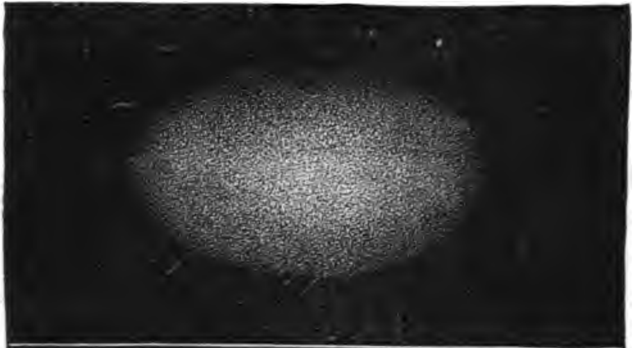
Fig. 18.



81. The nebulæ, properly so called, present a much greater variety of form than the stellar clusters. Some are circular, with more or less precision of outline. Some are elliptical, the oval outline having degrees of excentricity infinitely various, from one which scarcely differs from a circle, to one which is compressed into a form not sensibly different from a straight line. In short, the minor axis of the ellipses bears all proportions to the major axis, until it becomes a very small fraction of the latter.

To infer the real from the apparent forms of these objects with any certainty, there are no sufficient data. But in the cases in which the brightness increases rapidly towards the centre, which it very generally does, it may be probably conjectured that their forms are globular or spheroidal, for the reasons already explained in relation to the clusters, and this becomes the more probable when it is considered, that these nebulæ are in fact clusters, the stars of which are reduced to a nebulous patch by distance.

Fig. 19.



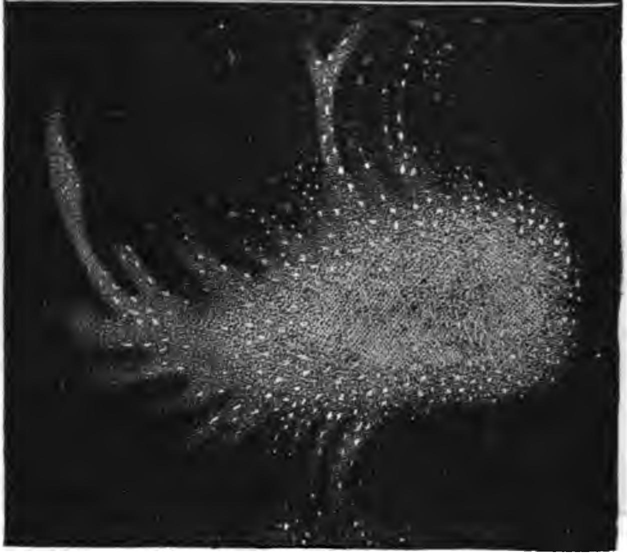


Fig. 20.

Nevertheless, these nebulæ may be strata of stars, of which the thickness is small compared with their other dimensions; and supposing their real outline to be circular, they will appear elliptical if the plane of the stratum be inclined to the visual line, and more or less excentrically elliptical, according as the angle of inclination is more or less acute. In cases in which the brightness does not increase in a striking degree from the edges inwards, this form is more probable than the globular or the spheroidal.

Nebulæ may be conveniently classed according to their apparent form and structure; but whatever arrangement may be adopted, these objects exhibit such varieties, assume such capricious and irregular forms, and undergo such strange and unexpected changes of appearance according to the increasing power of the telescope with which they are viewed, that it will always be found that great numbers of them will remain unavoidably unclassified.

82. Like individual stars, nebulæ are found to be combined in pairs too frequently to be compatible with the supposition, that such combinations arise from the fortuitous results of the small obliquity of the visual rays, which causes mere optical juxtaposition.

In figs. 21, 22, 23, and 24, four double nebulæ of this class are represented.

In fig. 21, the visual line passes between them without touching either, and they are consequently seen completely separated. They are in this case equal in magnitude.

Fig. 21.

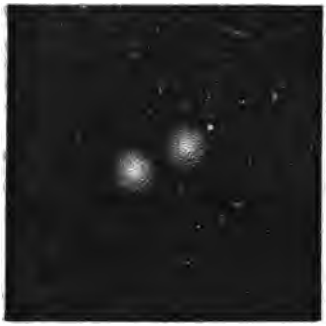
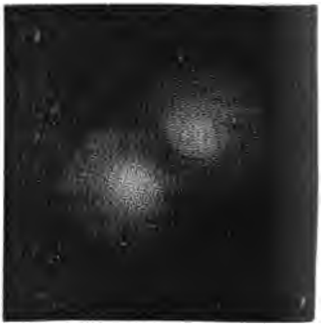


Fig. 22.



In fig. 22 they are also equal in magnitude, but the distance between their centres being less than their diameter, they partially overlay each other.

In figs. 23 and 24 they are unequal, and also partly overlay each other.

Fig. 23.

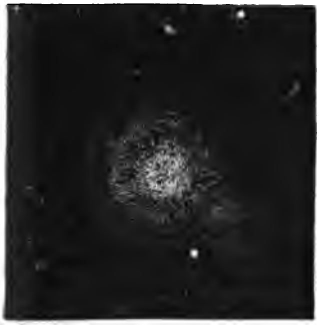
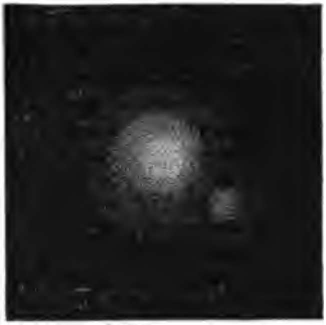


Fig. 24.



These double nebulæ are generally circular in their apparent, and therefore probably globular in their real form. In some cases they are resolvable clusters.

That such pairs of clusters are physically connected does not admit of a reasonable doubt, and it is highly probable that, like the binary stars, they move round each other, or round a common centre of attraction, although the apparent motion attending such revolution is rendered so slow by their immense distance that it can only be ascertained after the lapse of ages.

83. *Planetary Nebulæ.*—This class of objects derive their name from their close resemblance to planetary discs. They are in general either circular or very slightly oval. In some cases the disc is sharply defined, in others it is hazy and nebulous at the edges. In some the disc shows a uniform surface, and in some it has an appearance which Sir J. Herschel describes by the term *curdled.*

There is no reason to doubt that the constitution of these objects is the same as that of other nebulæ, and that they are in fact clusters of stars which by mutual proximity and vast distance are reduced to the form of planetary discs.

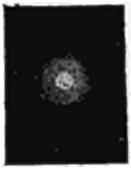
Nebulæ of this class, which are not numerous, present some remarkable peculiarities of appearance and colour. It has been already observed that, although the companion of a red individual of a double star appears blue or green, it is not certain that this is its real colour, the optical effect of the strong red of its near neighbour being such as would render a white star apparently blue or green, and no example of any single blue or green star has ever been witnessed. The planetary nebulæ, however, present some very remarkable examples of these colours. Sir J. Herschel indicates a beautiful instance of this, in a planetary nebula situate in the southern constellation of the Cross. The apparent diameter is 12″, and the disc is nearly circular, with a well-defined outline, and a "fine and full blue colour verging somewhat upon green." Several other planetary nebulæ are of a like colour, but more faint.

The magnitudes of these stupendous masses of stars may be conjectured from their probable distances. One of the largest, and therefore probably the nearest of them, is situate near the star β Ursæ majoris (one of the pointers). Its apparent diameter is 2′ 40″. Now, if this were only at the distance of 61 Cygni, whose parallax is known, it would have a diameter equal to seven times that of the extreme limit of the solar system; but as it is certain that its distance must be many times greater, it may be conceived that its dimensions must be enormous.

In fig. 25 is represented a small nebula of this class, drawn by Sir J. Herschel. It is situate near the star δ in the constellation Hercules (R A, $17^h\ 45^m$ N P D, 66° 53′), and is described as having a perceptible disc from 1″ to $1\frac{1}{2}$″ in diameter, surrounded by a faint nebula.

Fig. 25.

Fig. 26.



In fig. 26 is another similar object, situated a little to the north of the constellation of Lyra (R A $19^h\ 40^m$ N P D 39° 54′). A most curious object. A star of the 11th magnitude, surrounded by a very bright and perfectly round planetary nebula of uniform light. Diameter in R A 3·5″, perhaps a very little hazy at the edges. (Herschel.)

In fig. 27 is represented another of the same class, situated in (R A $13^h\ 29^m$ N P D 107° 1′) the constellation Virgo near the bright star *Spica*. Its entire diameter is 2′, being the 15th of that of the moon, and the diameter of the bright central part 10″ to 15″. It is described as a faint large nebula losing itself quite imperceptibly; a good type of its class. (Herschel.)

In fig. 28 is a nebula, situate in (R A $10^h\ 28^m$ N P D 35° 36′). It is described as a bright round nebula, forming almost a disc 15" diameter, surrounded by a very feeble atmosphere. (Herschel.)

Fig. 27.

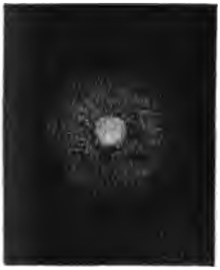
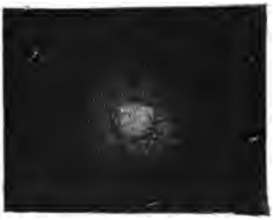


Fig. 28.



84. *Annular Nebulæ.*—A very few of the nebulæ have been observed to be annular. Until lately there were only four. The telescopes of Lord Rosse have, however, added five to the number, by showing that certain nebulæ formerly supposed to be small round patches are really annular. It is extremely probable, that many others of the smaller class of round nebulæ will prove to be annular, when submitted to further examination with telescopes of adequate power and efficiency.

In fig. 29 one of this class is given, the situation of which is (R A 8^h 47^m N P D 57° 11′) between the constellations of Gemini and Cancer. This object, drawn by Sir J. Herschel, is the annular nebula between β and γ Lyræ. He estimates its diameter at 6"·5. The annulus is oval, its longer axis being inclined at 57° to the meridian. The central vacuity is *not black*, but filled with a nebulous light. The edges are not sharply cut off, but ill defined; they exhibit a curdled and confused appearance, like that of stars out of focus. He considers it not well represented in the drawing.

Fig. 29.

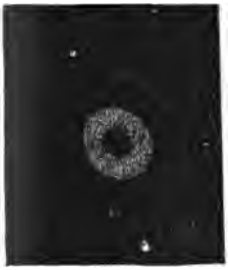


Fig. 30.

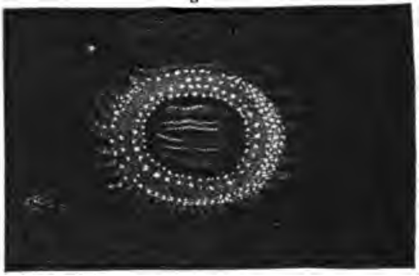
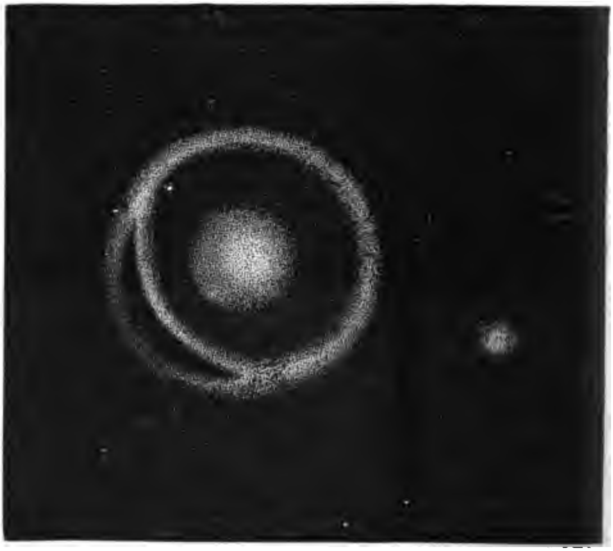


Fig. 30 is the same object as shown in the telescope of Lord Rosse. This drawing was made with the smaller telescope, three feet aperture, before the great telescope had been erected. The nebula was observed seven times in 1848, and once in 1849. With the large telescope, the central opening showed considerably more nebulosity than it appeared to have with the smaller instrument. It was also noticed, that several small stars were seen around it with the large instrument, which did not appear with the smaller one, from which it was inferred that the stars seen in the dark opening of the ring may possibly be merely accidental, and have no physical relation to the nebula. In the annulus near the extremity of the minor axis, several minute stars were visible.

85. *Spiral Nebulæ.*—The discovery of this class of objects, the most extraordinary and unexpected which modern research has yet disclosed in stellar astronomy, is due to Lord Rosse. Their general form and character may be conceived by referring to those represented in figs. 32 and 34. These extraordinary forms are so entirely removed from all analogy with any of the phenomena presented either in the motions of the solar system, or the comets, or those of any other objects to which observation has been directed, that all conjecture as to the physical condition

Fig. 31.

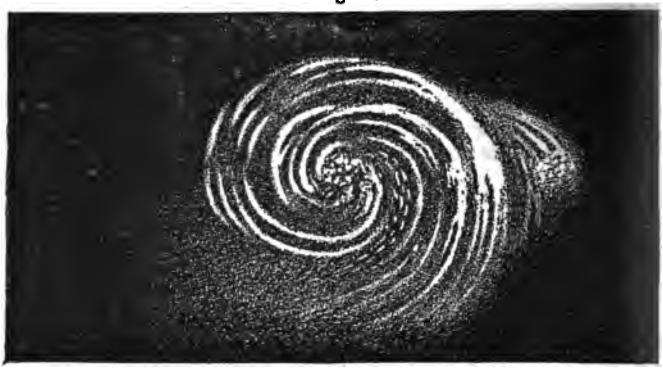


of the masses of stars which could assume such forms would be vain. The number of instances as yet detected, in which this form prevails, is not great; but it is sufficient to prove that the phenomenon, whatever be its cause, is the result of the operation of some general law. It is pretty certain, that when the same powerful instruments which have rendered these forms visible in objects which had already been so long under the scrutiny of the most eminent observers of the last hundred years, including Sir W. and Sir J. Herschel, aided by the vast telescopic powers at their disposition, without raising even a suspicion of their real form and structure, have been applied to other nebulæ, other cases of the same phenomenon will be brought to light. In this point of view it is much to be regretted, that the telescopes of Lord Rosse cannot have the great advantage of being used under skies more favourable to stellar researches, since the discovery of such forms as these not only requires instruments of such power as Lord Rosse alone possesses at present, but also the most favourable atmospheric conditions.

In connection with this class of objects, and indeed with the nebulæ generally, one of the most remarkable is situate (R A 13^h 33^m N P D 41° 56′); as shown in fig. 31, it was observed and drawn by Sir John Herschel. "This is," says that eminent astronomer, "in many respects, one of the most remarkable and interesting of its class, and has been submitted to elaborate examination by all the eminent observers." The distance of the centre of the small nebula from that of the large one, is given by Messier, as 4′ 35″, which may serve as a *modulus* for its other dimensions. It was described by Sir W. Herschel as a bright round nebula, surrounded by a halo or glory, and attended by a companion. Sir J. Herschel observed this object, and represented it as in the figure. He noticed the partial division of the ring, as if it were split, as its most remarkable and interesting feature, and inferred that, supposing it to consist of stars, the appearance it would present to an observer, placed on a planet attached to one of them excentrically situate towards the north preceding quarter of the central mass, would be exactly similar to that of the milky way as seen from the earth, traversing in a manner precisely similar the firmament of large stars, into which the central cluster would be seen projected, and (owing to its greater distance) appearing like it to consist of stars much smaller than those in other parts of the heavens. "Can it be," asks Sir J. Herschel, "that we have here a brother system, bearing a real physical resemblance and strong analogy of structure to our own?" Sir J. Herschel further argues, that all idea of symmetry caused by rotation must be relinquished, considering that the elliptical form of the inner subdivided portion indicates with extreme probability an elevation of that part above the plane of the rest; so that the real form must be that of a ring split through half its circumference, and having the split portions set asunder at an angle of 45°.

Fig. 32 is the same object as shown by Lord Rosse's telescope. This shows, in a striking manner, how entirely the appearances of these objects are liable to be varied by the increased magnifying power and greater efficiency of the telescope through which they are viewed. It is evident, that very little resemblance or analogy is discoverable between fig. 31 and fig. 32. Lord Rosse, however, says that if Sir John Herschel's be placed as it would be seen with a Newtonian telescope, the bright convolutions of the spiral shown in his own would be recognised in the appearance which Sir J. Herschel supposed to be that which would be produced by a split or divided ring. Lord Rosse further observes that, with each increase of optical power, the structure of this object becomes more complicated and more unlike anything which could be supposed to be the result of any form of dynamical law of which we find a counterpart in our system. The connection of the companion with the principal nebula, of which there is not the least doubt, and which is represented in the sketch, adds, in Lord Rosse's opinion, if possible, to the difficulty of forming any conceivable hypothesis. That such a system should exist without internal movement he considers in the last degree improbable. Our conception may be aided, by uniting with the idea of motion the effects of a resisting medium; but it is impossible to imagine such a system in any point of view, as a case of mere statical equilibrium. Measurements he therefore considers of the highest interest, but of great difficulty.

Fig. 32.



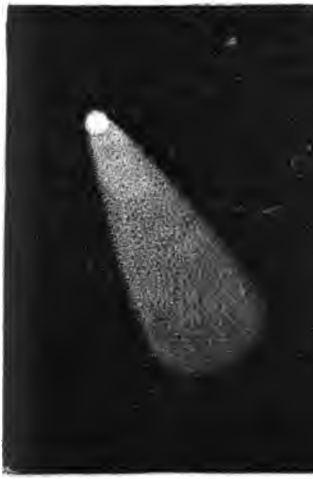


Fig. 50.

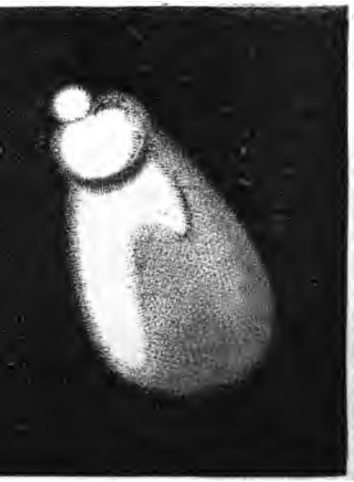


Fig. 51.

THE STELLAR UNIVERSE.

CHAPTER VI.

Spiral nebulæ (continued).—86. Number of nebulæ.—87. The Dumb-Bell nebula as observed by Sir J. Herschel and Lord Rosse.—88. Various nebulæ figured by the same observers.—89. Large irregular nebulæ.—90. Rich cluster in the Centaur.—91. The great nebula in Orion.—92. The great nebula in Argo.—93. Magellanic clouds.

IN fig. 33 is reproduced a drawing by Sir J. Herschel of a large nebula having a diameter estimated by him at 3′, or a tenth of that of the moon. This object is situate in R A 9^h 22^m N P D 67° 45′, and therefore near the northern part of the constellation of Leo minor. This is described by Sir John Herschel as a very bright extended nebula, with an approach to a second nucleus, which, however, is very faint.

Fig. 34 is the same object as shown by Lord Rosse's telescope. This object was first observed with the great telescope, 24th March, 1846, when a tendency to an annular or spiral form was discovered. On the 9th March, 1848, in more favourable weather, the spiral form was distinctly seen in an oblique direction. The nebula was well resolved, particularly towards the centre, where it was very bright.

Another most extraordinary spiral nebula is shown in fig. 35, p. 17. It has been the subject of examination by all eminent observers

Fig. 33.

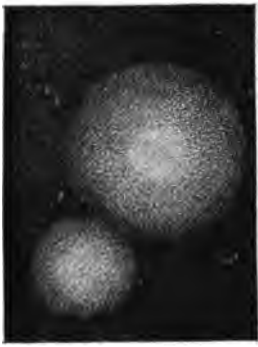
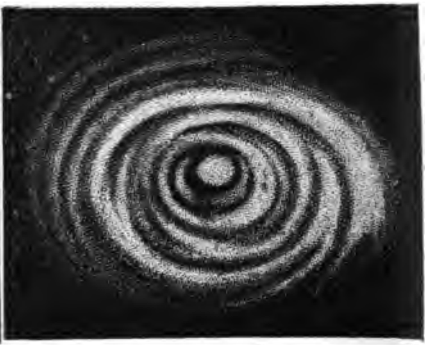


Fig. 34.

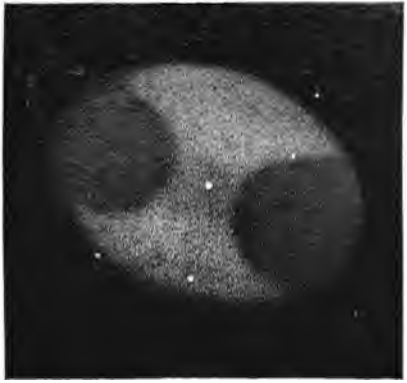


since the time of Messier, in whose catalogue it is No. 99. The spiral form of the nebula, represented in fig. 32, was discovered by Lord Rosse, in the early part of 1845. In the spring of 1846, that represented in the present figure was discovered. The spiral form is here also presented, but of a different character. Lord Rosse conjectures, that the nebula No. 2370, and 3239 of Herschel's southern catalogue, are very probably objects of a similar character. As Herschel's telescope did not reveal any trace of the form of this nebula, it is not surprising that it did not disclose the spiral form presumed to belong to the others, and it is not, therefore unreasonable to hope, according to his lordship, that whenever the southern hemisphere shall be re-examined with instruments of greater power, these two remarkable nebulæ will yield some interesting results.

Lord Rosse has discovered other spiral nebulæ, but they are comparatively difficult to be seen, and the greatest powers of the instrument are required to bring out the details.

In fig. 36 is another nebula having the spiral character, and a most singular form. Its situation is R A 1^{h} 24^{m} N P D 60° 31′, and is therefore in the northern part of the constellation Pisces. It is of great magnitude, having a diameter not less than half that of the moon. This object has been the subject of observation by all the eminent observers. Sir John Herschel describes it as enormously large, growing very gradually brighter towards the middle, and having a star of the 12th magnitude, north, following the nucleus, and being characterised by irregularities of light, and even by feeble subordinate nuclei and many small stars. The drawing represents it as seen with the more powerful telescope of Lord Rosse. A tendency to a spiral form was distinctly seen on the 6th, 10th, and 16th September, 1849. The whole object was involved in a faint nebulosity, which probably extends past several knots which lie about it in different directions.

Fig. 37.



86. The forms and magnitudes of the nebulæ are so infinitely various, that it is impossible to reduce them to any definite classification. Their number also is quite unbounded. The catalogues of Sir J. Herschel contain above 4000, of which the places are assigned, and the magnitudes, forms, and apparent characters described. As observers are multiplied, and the telescope improved, and especially when the means of observation have been extended to places that are more favourable for such observations, it may be expected that the number observed will be indefinitely augmented.

87. In fig. 37, we have reproduced the drawing of a well-known nebula by Sir John Herschel. This has been called, from its apparent form, the Dumb Bell nebula. Its situation is R A $19^h\ 52^m$ N P D 67° 44′, and consequently between the constellations of Vulpa minor and Lyra. Sir John Herschel describes it as a nebula shaped like a dumb-bell, double-headed shot, or hour-glass, the elliptic outline being completed by a more feeble nebulous light. The axis of symmetry through the centres of the two chief masses inclined at 30° to the meridian. Diameter of elliptic light from 7′ to 8′. Not resolvable, but four stars are visible on it, of the 12th, 13th, and 14th magnitude. The southern

head is denser than the northern. This extraordinary object was also observed by Sir W. Herschel, who recognised the same

Fig. 38.

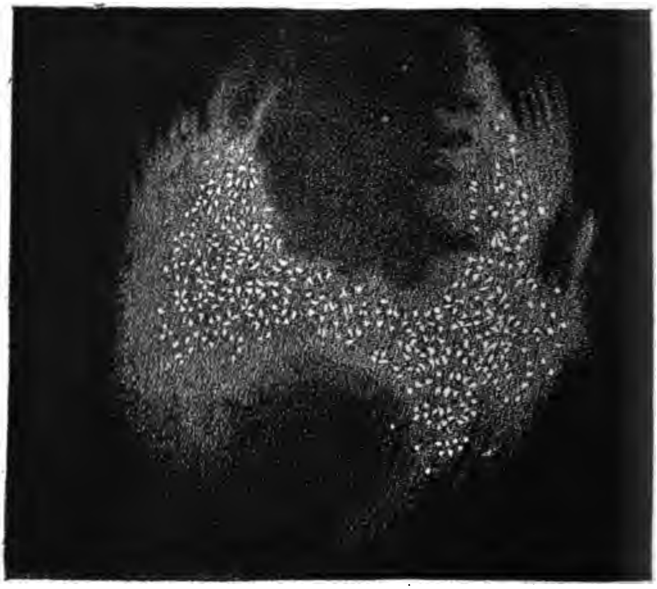
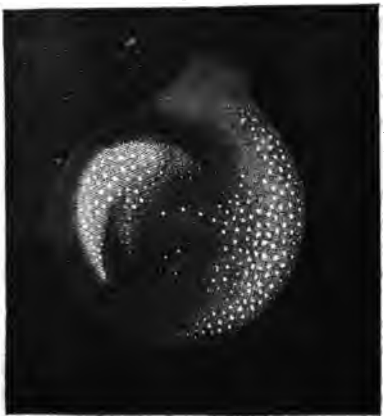


Fig. 39.



peculiar form. Sir J. Herschel considers that the most remarkable circumstance attending it is the faint nebulosity which fills up the lateral concavities of its form, and in fact converts them into protuberances, so as to render the whole outline a regular ellipse, having for its shorter axis the common axis of the two bright masses. If it be regarded as a mass in rotation, it is around this shorter axis it must revolve. In that case, he considers that its real form must be that of an oblate spheroid; and as it does not follow that the brightest portions must be of necessity the densest, this supposition would not be incompatible with dynamical laws, at least supposing its parts to be capable of exerting pressure on each other. But if it consist of distinct stars this cannot be admitted, and we must then have recourse to other suppositions to account for the maintenance of its form. Sir John Herschel, it will be observed, failed to resolve this nebula.

Fig. 38 is the same object as shown by the telescope of Lord Rosse, three feet aperture, twenty-seven feet focal length.

Fig. 39 is the same object as shown with the great telescope of Lord Rosse, six feet aperture, fifty-three feet focal length.

The difference between these two representations and that given by Sir John Herschel of the same object, will illustrate in a very striking manner the observations already made on the effects of different magnifying and defining powers upon the appearance of the object under examination. These three figures could scarcely be conceived to be representations of the same object.

To explain the difference observable between the drawing fig. 38, made with the smaller telescope, and the drawing fig. 39, made with the larger instrument, Lord Rosse observes, that while the application of a high magnifying power brings out minute stars not visible with lower powers, it completely extinguishes nebulosity which the lower powers render visible. The optical reason for this will be easily perceived; the circumstance was nevertheless overlooked when the observations were made from which the drawing fig. 38 was taken. Only one magnifying power, and that a very high one, was used on that occasion, the consequence of which was that, although the two knobs of the dumb-bell were more fully resolved, the nebulous matter filling the intermediate space, which Herschel considered to be the most remarkable feature of this nebula, was entirely extinguished in

Fig. 40.

the optical image. If on that occasion a second eye-piece had been used of lower power, the intermediate nebulous matter would have been seen, as represented in the drawing, and the drawing would be as perfect as, and nearly identical with, that obtained with the greater telescope, a lower power being used.

Fig. 41.

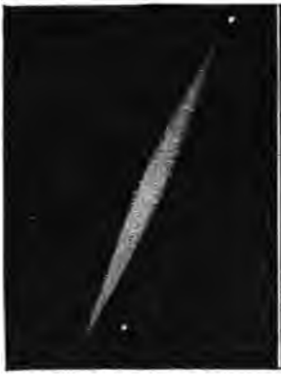


Fig. 42.

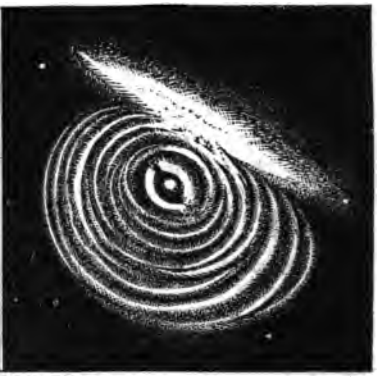


Fig. 43.

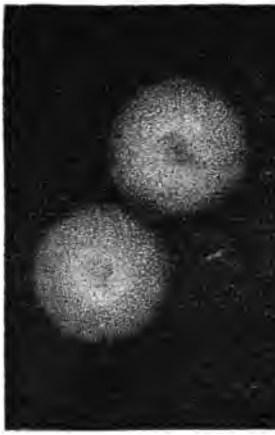
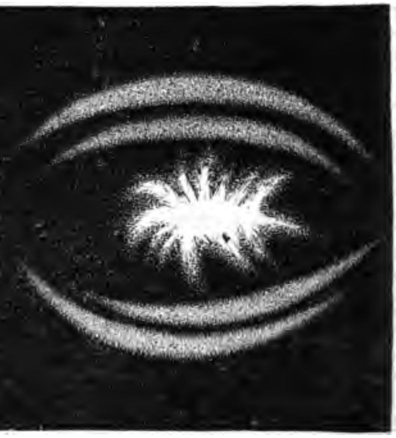


Fig. 44



It will be observed that the general outline of this remarkable object which is so geometrically exact as seen with the inferior power used by Sir John Herschel, is totally effaced by the application of the higher powers used by Lord Rosse, and consequently Sir John Herschel's theoretical speculations based upon this particular form, must be regarded as losing much of their force, if not wholly inadmissible; and this is an example proving how unsafe it is to draw any theoretical inferences from apparent peculiarities of form or structure in these objects, which may be only the effect of the imperfect impressions we receive of them, and which, consequently, disappear when higher telescopic powers are applied. The case of the nebula represented in figs. 31 and 32, presents another striking example of the force of these observations.

88. In fig. 40 is a nebula drawn by Sir J. Herschel, who describes it as a faint large round nebula, which, by attentive examination, may be seen to be composed of excessively minute stars, appearing like points rubbed out. It is, in fact, a globular cluster.

In fig. 41, is a nebula situated in R A 22^h 56^m, N P D 78° 36′, and therefore in the southern part of the constellation of Pegasus. The length of this, as estimated by Sir J. Herschel, is 2′, or the 15th part of the moon's diameter, while the breadth is only half a minute, or the 60th part of the breadth of the lunar disk. It is shown in fig. 41 as it appeared in the telescope of Sir J. Herschel. It is described by him as pretty bright and resolvable, and extended between two small stars, having two very small stars visible in it.

In fig. 42 is shown the same object as seen in Lord Rosse's telescope. It was frequently observed, both by Lord Rosse himself and several of his friends, and the drawing represents the form with great accuracy. It was doubtful whether the form was strictly spiral, or whether it were not more properly annular.

In fig. 43 is shown a double nebula situate in R A 7^h 15^m, N P D 60° 11′, and therefore near the bright star Castor. It is drawn by Sir J. Herschel, who describes it as a curious bright double or an elongated bicentral nebula.

In fig. 44 is the same object as shown by Lord Rosse's telescope on 22nd December, 1848. A bright star was visible between the nebulæ from which tails and curved filaments issued. The existence of an annulus surrounding the two nebulæ was suspected.

In figs. 45, 46 are views of the same nebula, as seen by Sir J. Herschel and Lord Rosse. This object is situate in R A 11^h 10^m. N P D 75° 59′, and therefore between the two brightest stars of the constellation Leo. Its length is 4′ or about the 7th of the moon's diameter. It is described by Sir John Herschel as large, elliptical in form, with a round nucleus, and growing gradually brighter towards the middle.

In fig. 46 it is given as shown by Lord Rosse's telescope, 31st March, 1848. Described as a curious nebula, nucleus resolvable, having a spiral or annular arrangement about it. It was also observed with the same results on the 1st and 3rd April.

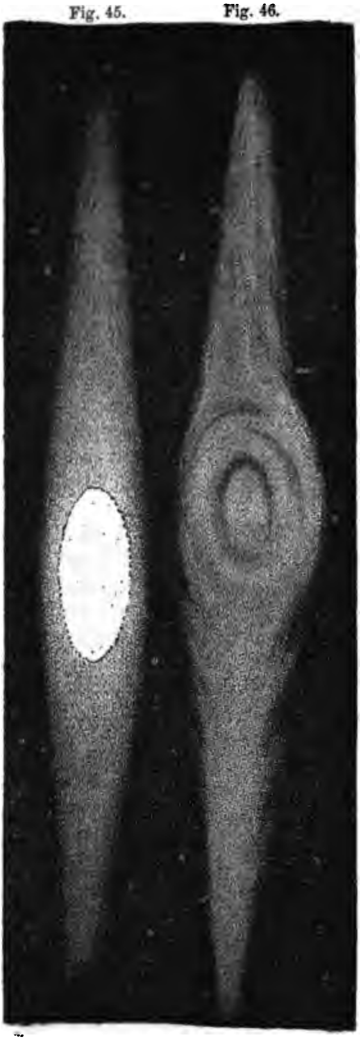


Fig. 45. Fig. 46.

A nebula, situate in R A 15^h 2^m, N P D 33° 35′, is shown in fig. 47, its length being 50″ and breadth 20″.

This nebula was not figured by Sir John Herschel; but is described by him as an object very bright, and growing much brighter towards the middle. The drawing represents the object as seen in Lord Rosse's telescope, in April, 1848. It is described by Lord Rosse as a very bright resolvable nebula, but that none of the component stars could be distinctly seen even with a magnifying power of 1000. A perfectly straight longitudinal division appears in the direction of the major axis of the ellipse. Resolvability was strongly indicated towards the nucleus. According to Lord Rosse, the proportion of the major axis to the minor axis was 8 to 1; much greater than the estimate of Sir John Herschel.

In figs. 48, 49 are given two views of the same nebula by Sir J. Herschel and Lord Rosse. Its situation is R A 12^h $33,^m$ N P D

56° 30′. It is therefore near the northern limit of the Coma Berenices. It is described by Sir John Herschel as a nebula of enormous length, extending across an entire field of 15′, the nucleus not being well defined. It was preceded by a star of the tenth magnitude, and that again by a small faint round nebula, the whole forming a fine and very curious combination.

Fig. 47

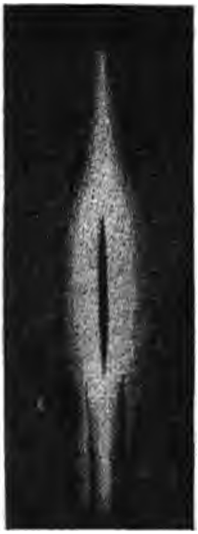


Fig. 48. Fig. 49

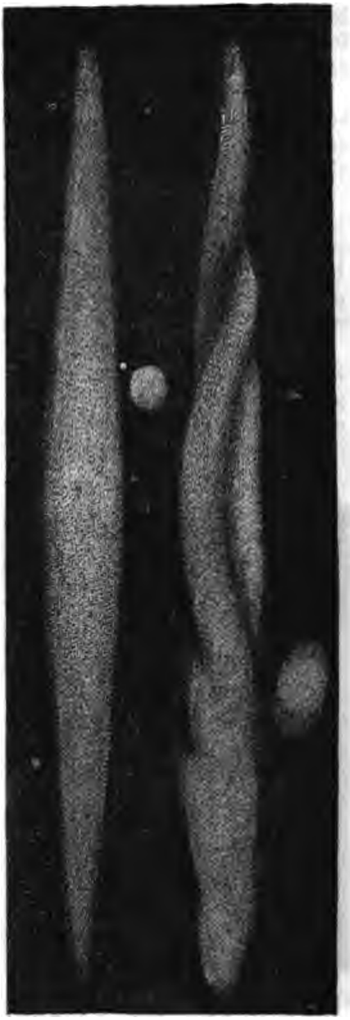


Fig. 49 is the same object as shown by Lord Rosse's telescope on 19th April, 1849. The drawing is stated to be executed with great care, and to be very accurate. A most extraordinary object, masses of light appearing through it in knots.

In fig. 50, p. 33, is represented a nebula situate in R A 6^h 30^m, N P

D 81° 30′. It is therefore situate about midway between the bright star Procyon and the shoulders of the constellation Orion. This object is described by Sir John Herschel as a star of the 12th magnitude, with a bright cometic branch issuing from it, 60″ in length, forming an angle of 60° with the meridian, passing through it. The star is described as ill-defined, the apex of the nebula coming exactly up to it, but not passing it.

Fig. 51, p. 33, is the same object as seen with Lord Rosse's telescope on 16th January, 1850. Lord Rosse observed that the two comparatively dark spaces, one near the apex and the other near the base of the cone, are very remarkable.

In fig. 52, p. 193, Vol. vii., is represented a nebula situated in R A 11^h 5^m, N P D 34° 3′, having a diameter equal to about the 90th part of that of the moon. It is drawn and described by Sir John Herschel as a large uniform nebulous disk, very bright and perfectly round, but sharply defined, and yet very suddenly fading away into darkness. A most extraordinary object.

Fig. 53, p. 193, Vol. vii., is the same object as shown by Lord Rosse's telescope. Two stars considerably apart, seen in the central part of the nebula. A dark penumbra around each spiral arrangement with stars as apparent centres of attraction. Stars sparkling in it and in the nebula resolvable. Lord Rosse saw two large and very dark spots in the middle, and remarked that all round its edge the sky appeared darker than usual.

Fig. 54.

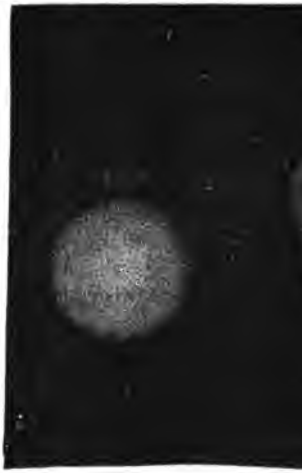
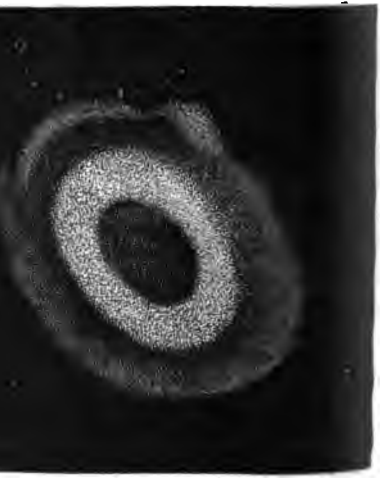


Fig. 55.



In fig. 54 is represented a nebula situated in R A $23^h\ 18^m$, N P D 48° 24′, as drawn by Sir John Herschel, who describes it as a fine planetary nebula. With a power of 240 it was beautifully defined, light, rather mottled, and the edges the least in the world unshaped. It is not nebulous, but looks as if it had a double outline, or like a star a little out of focus. It is perfectly circular.

Fig. 55 is the same object as shown in Lord Rosse's telescope, 16th—19th December 1848. A central dark spot surrounded by a bright annulus.

In fig. 56, p. 1, vol. viii., is a nebula situate in R A $20^h\ 54^m$, N P D 102° 3′. Diameter 10″ to 12″ according to Herschel, but 25″ by 17″ according to Struve, who gives it a more oval form. This figure is that given by Sir John Herschel, who describes it as a fine planetary nebula with equable light and bluish white colour.

Fig. 57, p. 1, vol. viii., is the same object as shown by Lord Rosse's telescope. Like a globe surrounded by a ring such as that of Saturn, the usual line being in the plane of the ring.

In fig. 58 is a nebula drawn by Sir J. Herschel, situate in R A $7^h\ 19^m\ 8^s$, N P D 68° 45′. Described as a star exactly in the centre of a bright circular atmosphere 25″ in diameter, the star being quite stellar, and not a mere nucleus, and is a most remarkable object.

Fig. 58.

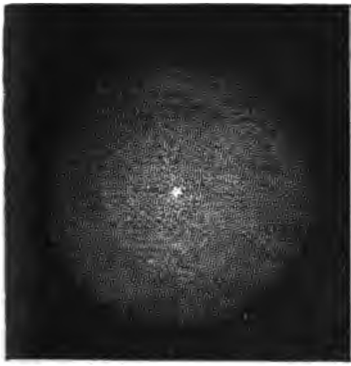


Fig. 59.

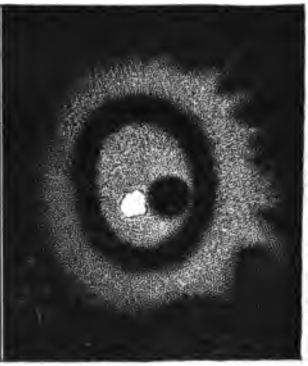
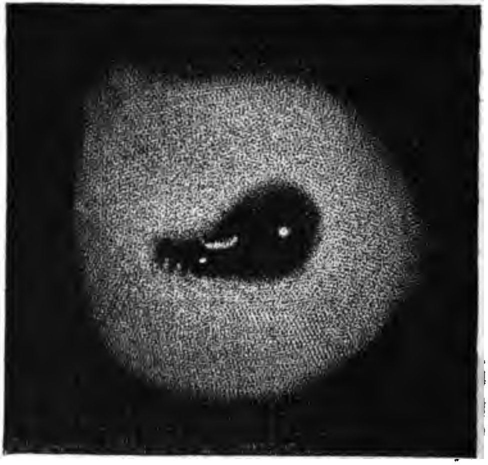


Fig. 59 is the same object as shown by Lord Rosse's telescope on 20th February, 1849; described by him as a most astonishing object. It was examined in January 1850, with powers of 700 and 900, when both the dark and bright rings seemed unequal in breadth.

In fig. 60 is represented a drawing by Lord Rosse, made with his large telescope, of a nebula situate in R A $5^h\ 27^m$, N P D 96° 2′. This nebula surrounds the small star ι Orionis, and has a diameter equal to about a tenth part of that of the moon.

Fig. 60.



89. All the nebulæ described above are objects generally of regular form, and subtending small visual angles. There are others, however, of a very different character, which cannot be passed without some notice. These objects cover spaces on the firmament, many nearly as extensive as, and some much more extensive than, the moon's disk. Some of them have been resolved. Of those which are larger and more diffused, some exhibit irregularly shaped patches of nebulous light, affecting forms resembling those of clouds, in which tracts are seen in every stage of resolution, from nebulosity irresolvable by the largest and most powerful telescopes, to stars perfectly separated like parts of the milky way, and "clustering groups sufficiently insulated and condensed to come under the designation of irregular and, in some cases, pretty rich clusters. But, besides these, there are also nebulæ in abundance, both regular and irregular; globular clusters, in every state of condensation, and objects of a nebulous character quite peculiar, which have no analogy in any other part of the heavens."[*]

---

[*] Herschel, Outlines of Astronomy, p. 613.

90. The star ω Centauri presents one of the most striking examples of the class of large diffused clusters. It is nearly round, and has an apparent diameter equal to two-thirds of that of the moon. This remarkable object was included in Mr. Dunlop's catalogue ("Phil. Trans." 1828); but it is from the observations of Sir John Herschel, at the Cape, that the knowledge of its splendid character is derived. That astronomer pronounces it, beyond all comparison, the richest and largest object of the kind in the heavens. The stars composing it are literally innumerable; and as their collective light affects the eye hardly more than that of a star of the fifth magnitude, the minuteness of each of them may be imagined. The apparent magnitude of this object is such that, when it was concentric with the field of Sir J. Herschel's 20-feet telescope, the straggling stars at the edges were beyond the limit of the field. In stating that the diameter is two-thirds of the moon's disk, it must be understood to apply to the diameter of the condensed cluster, and not to include the straggling stars at the edges. When the centre of the cluster was brought to the edge of the field, the outer stars extended fully half a radius beyond the middle of it.*

The appearance of this magnificent object resembles that shown in fig. 18, only that the stars are much more densely crowded together, and the outline more circular, indicating a pretty exact globe as the real form of the mass.

91. *The great nebula in Orion.*—The position of this extraordinary object is in the sword-handle of the figure which forms the constellation of Orion. It consists of irregular cloud-shaped nebulous patches, extending over a surface about 40′ square; that is, one whose apparent breadth and height exceed the apparent diameter of the moon by about one-third, and whose superficial magnitude is, therefore, rather more than twice that of the moon's disk. Drawings of this nebula have been made by several observers, and engravings of them have been already published in various works.

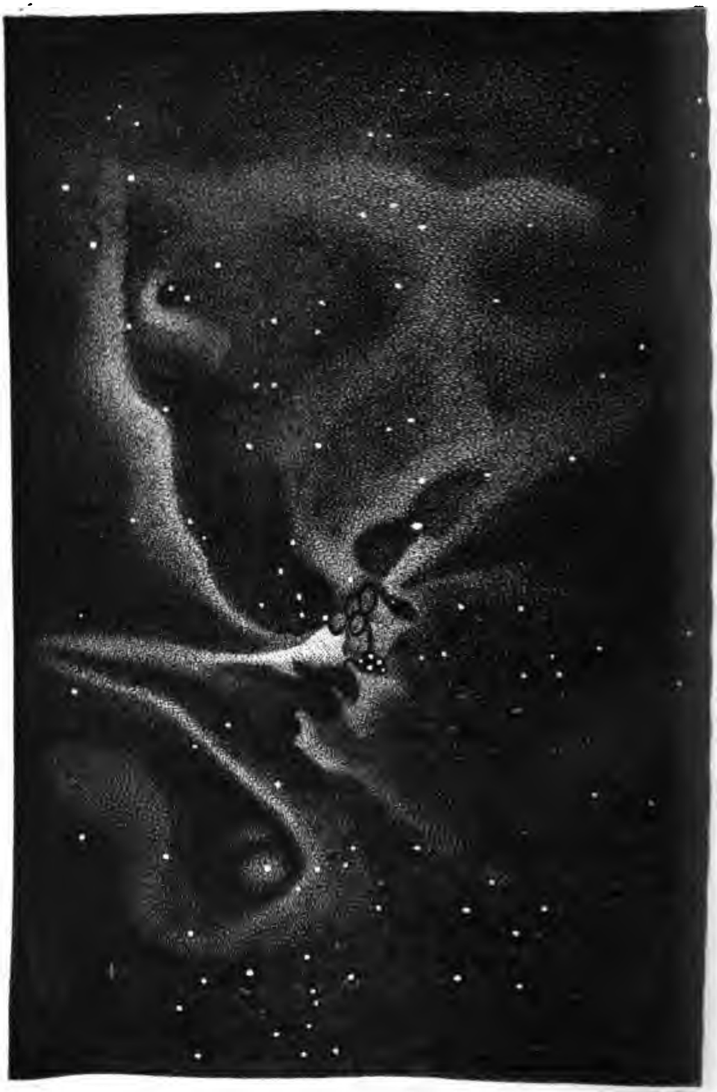
In fig. 61 is given a representation of the central part of this object. The portion here represented has a height and breadth about one-sixth less than the diameter of the moon. An engraving upon a very large scale, of the entire extent of the nebula, with an indication of the various stars which serve as a sort of landmarks to it, may be seen by reference to Sir J. Herschel's "Cape Observations," accompanied by the interesting details of his observations upon it.

Sir J. Herschel describes the brightest portion of this nebula as

---

* Cape Observations, p. 21.

Fig. 61.



resembling the head and yawning jaws of some monstrous animal, with a sort of proboscis running out from the snout. The stars scattered over it probably have no connection with it, and are doubtless placed much nearer to our system than the nebula, being visually projected upon it. Parts of this nebula, when submitted to the powers of Lord Rosse's telescope, show evident indications of resolvability.

92. An object of the same class is shown in fig. 62, p. 177, Vol. vii., and presenting like appearances; it is diffused around the star η in the constellation Argo, and formed a special subject of observation by Sir J. Herschel, during his residence at the Cape. An engraving of it on a large scale, giving all its details, may be seen in the "Cape Observations." The position of the centre of the nebula is, R A 10° 38′ 38″, N P D 148° 47′.

This object consists of diffused irregular nebulous patches, extending over a surface measuring nearly 7^m in right ascension, and 68′ in declination; the entire area, therefore, being equal to a square space, whose side would measure one degree. It occupies, therefore, a space on the heavens about five times greater than the disk of the moon.

The part of the nebula immediately surrounding the central star, is represented in fig. 62. The space here represented measures about one-fourth of the entire extent of the nebula, in declination, and one-third in right ascension, and about a twelfth of its entire magnitude.

No part of this remarkable object has shown the least tendency to resolvability. It is entirely compressed within the limits of that part of the milky way which traverses the southern firmament, the stars of which are seen projected upon it in thousands. Sir J. Herschel has actually counted 1200 of these stars projected upon a part of this nebula, measuring no more than 28′ in declination, and 32′ in right ascension, and he thinks that it is impossible to avoid the conclusion, that in looking at it we see through and beyond the milky way, far out into space through a starless region, disconnecting it altogether with our system.

93. The Magellanic clouds are two extensive nebulous patches also seen on the southern firmament, the greater called the *nubecula major*, being included between R A 4^h 40^m, and 6^h 0^m and N P D 156° and 162°, occupying a superficial area of 42 square degrees; and the other called the *nubecula minor*, being included between R A 0^h 21^m and 1^h 15^m and between N D P 162° and 165°, covering about 10 square degrees.

These nebulæ consist of patches of every character, some irresolvable, and others resolvable in all degrees, and mixed with clusters; in fine, having all the characters already explained in the cases of the large diffused nebulæ described above. So great is the number of distinct nebulæ and clusters crowded together in these tracts of the firmament, that 278, besides 50 or 60 outliers, have been enumerated by Sir J. Herschel, within the area of the nubecula major alone.

LONDON, *December*, 1855.

WORKS

PUBLISHED BY

WALTON AND MABERLY,

UPPER GOWER STREET, AND IVY LANE, PATERNOSTER ROW.

THE New Testament Quotations, Collated with the Scriptures of the Old Testament in the original Hebrew, and the Version of the LXX; and with the other writings, Apocryphal, Talmudic, and Classical, cited or alleged so to be. With Notes and a complete Index. By Henry Gough, 8vo, 16*s*.

The Chinese Rebel Chief Hung-siu-tsuen; His History, and the Origin of the Present Insurrection. By the Rev. THEODORE HAMBERG, Hong-Kong. Edited by GEORGE PEARSE, Foreign Secretary of the Chinese Evangelisation Society. Foolscap 8vo, 1*s*. 6*d*. cloth.

London Quarterly Review, No. IX., Price 6*s*., for October, contains—1. Bunsen's Egypt.—2. Life and Death in Coal Mines.—3. The Fall of the Byzantine Empire.—4. Nicholas Copernicus.—5. Recent Apologies for the Greek Church.—6. The General Post Office.—7. Home Heathenism.—8. Alfred Tennyson: Maud, and other Poems.—9. Exposition of the Fine Arts in Paris. Brief Literary Notices.

Far above Rubies. A MEMOIR OF HELEN S. HERSCHELL. By her Daughter. Edited by the Rev. RIDLEY H. HERSCHELL. Foolscap 8vo, 6*s*. 6*d*. cloth.

⁂ The Volume also contains the "Bystander," a Series of Papers by Mrs. Herschell, on the following subjects:—1. Introductory.—2. Education.—3. The Law of Consideration.—4. The Deserted Village.—5. Sectarianism.—6. High Church Principles.—7. Love.—8. Elmwood.—9. Spiritual Declension.—10. The Fête.—11. Party Spirit.—12. Training Children.—13. Home Education.—14. An Amusing Companion.—15. Christian Benevolence.—16. Special Providence.—17. Moral Influence.—18. Christian Society.—19. Human Responsibility.

A Memoir of the Rev. James Crabb, LATE OF SOUTHAMPTON. THE "GIPSY ADVOCATE." By JOHN RUDALL, of Lincoln's Inn, Barrister-at-Law. One Vol., Crown 8vo. With a Portrait on Steel. 6*s*. cloth.

"The Author has presented us with a faithful portraiture of Mr. Crabb's life, character, persevering labours, and never-tiring zeal in the service of his Divine Master."—*Hampshire Independent.*

The Jews. A Brief Sketch of their Present State and Future Expectations. By RIDLEY H. HERSCHELL. Ninth Thousand. Foolscap 8vo, 1*s*. 6*d*.

The Crystal Palace. An Essay Descriptive and Critical. From the London Quarterly Review. 8vo, 1*s*.

EMBOSSED BOOKS FOR THE BLIND.

BY MR. FRERE.

OLD TESTAMENT.

Genesis, 8*s*.—Exodus, 7*s*.
Joshua, 4*s*. 6*d*.—Judges, 4*s*. 6*d*.
Samuel I., 6*s*.—Samuel II., 5*s*. 6*d*.
Job, 5*s*.—Proverbs, 5*s*. 6*d*.
Psalms, Part I., 6*s*. 6*d*.
Psalms, Part II., 5*s*. 6*d*.
Isaiah, 7*s*. 6*d*.
Daniel, Esther, and Ruth, 5*s*. 6*d*.
Morning Prayers, 2*s*.
Shepherd of Salisbury Plain, 2*s*.
Olney Hymns, 2*s*.

NEW TESTAMENT (In 8 Vols.)

Matthew, 6*s*.
Mark, 5*s*. 6*d*.
Luke, 7*s*.
John, 5*s*. 6*d*.
Acts, 7*s*.
Romans to Corinthians, 6*s*.
Galatians to Philemon, 5*s*. 6*d*.
Hebrews to Revelations, 7*s*.
A Grammar, 1*s*.
Five Addresses to those who wish to go to Heaven, 1*s*. 6*d*.

Art of Teaching to Read by Elementary Sounds, 1*s*. 6*d*.

JURISPRUDENCE.

ELEMENTS of Jurisprudence. By CHARLES JAMES FOSTER, M.A., LL.D., Professor of Jurisprudence in University College, London. Crown 8vo, 5*s*. cloth.

"Mr. Foster treats his subject in a masterly manner, and his volume may be read with profit both by students and men of the world."—*Athenæum.*

ENGLISH COMPOSITION.

ELEMENTS of Rhetoric; A Manual of the Laws of Taste, including the Theory and Practice of Composition. By SAMUEL NEIL, Author of "The Art of Reasoning." Large 12mo, 4*s*. 6*d*. cloth.

LOGIC.

THE Art of Reasoning; A Popular Exposition of the Principles of Logic, Inductive and Deductive, with an Introductory Outline of the History of Logic, and an Appendix on Recent Logical Developments. By SAMUEL NEIL. Crown 8vo, 4*s*. 6*d*.

"This work is of undoubted merit. It displays a great thoughtfulness and research, and contains a vast amount of useful information on the subject of which it treats. The author seems to have thoroughly mastered his subject, and to the illustration of it has skilfully applied his extensive and varied knowledge."—*Glasgow Constitutional.*

An Investigation of the Laws of Thought, on which are founded the Mathematical Theories of Logic and Probabilities. By GEORGE BOOLE, Professor of Mathematics in Queen's College, Cork. One Vol. 8vo, 14*s*. cloth.

Formal Logic; or, the Calculus of Inference necessary and PROBABLE. By AUGUSTUS DE MORGAN, Professor of Mathematics in University College, London. Cheap Issue, 8vo, 6*s*. 6*d*.

HISTORY, ANTIQUITIES, &c.

DICTIONARY of Greek and Roman Geography. Edited by WILLIAM SMITH, LL.D., Editor of the Dictionaries of "Greek and Roman Antiquities," and of "Biography and Mythology." With very numerous Illustrations on Wood. Volume I. (1100 pages), 1*l*. 16*s*. cloth lettered.

The Work is continued in Quarterly Parts, each 4*s*., and will be completed in Two Volumes. Parts 14 and 15 (Double Part) on the 1st of January, 1856, bringing down the work to the letter R.

Dictionary of Greek and Roman Biography and Mythology. Edited by WILLIAM SMITH, LL.D., Classical Examiner in the University of London. Medium 8vo. Illustrated by numerous Engravings on Wood. Complete in Three Vols., 5*l*. 15*s*. 6*d*.

Dictionary of Greek and Roman Antiquities. By various Writers. Edited by Dr. WILLIAM SMITH. Second Edition. Revised throughout, with very numerous Additions and Alterations. One thick Volume, medium 8vo, with several hundred Engravings on Wood, 2*l*. 2*s*.

A New Classical Dictionary of Ancient Biography, Mythology, AND GEOGRAPHY. Edited by Dr. WILLIAM SMITH. New Edition. One Volume, 8vo, 15*s*. cloth.

This work comprises the same subjects as are contained in the well-known Dictionary of Lemprière, avoiding its errors, supplying its deficiencies, and exhibiting in a concise form the *results* of the labours of modern scholars. It will thus supply a want that has been long felt by most persons engaged in tuition.

A Smaller Dictionary of Antiquities; Selected and Abridged from the "Dictionary of Greek and Roman Antiquities." By WILLIAM SMITH, LL.D. New and Cheaper Edition. One small Volume, Two Hundred Woodcuts, 7*s.* 6*d.* cloth.

A Smaller Classical Dictionary. Abridged from the larger work. By Dr. WILLIAM SMITH. Cheaper Edition. Two Hundred Woodcuts, Crown 8vo, 7*s.* 6*d.* cloth.

The Odes of Horace, translated into Unrhymed Metres. With Introductions and Notes. By F. W. NEWMAN, Professor of Latin, University College, London. Crown 8vo. 5*s.* cloth.

Niebuhr's History of Rome, from the Earliest Times to the FALL OF THE WESTERN EMPIRE. Translated by BISHOP THIRLWALL, ARCHDEACON HARE, Dr. WILLIAM SMITH, and Dr. SCHMITZ. Fourth and Cheaper Edition. Three Vols. 8vo, 36*s.*

Niebuhr's Lectures on Roman History. Translated and Edited by LEONHARD SCHMITZ, Ph. D., Rector of the High School of Edinburgh. New and Cheaper Edition, in Three Vols. 8vo, 24*s.*

Niebuhr's Lectures on Ancient History, comprising the Asiatic Nations, the Egyptians, Greeks, Carthaginians, and Macedonians. Translated by Dr. L. SCHMITZ. Three Vols. 8vo, 1*l.* 11*s.* 6*d.*

In reference to Babylonia, Assyria, and Egypt, it is particularly interesting to notice how clearly the historian foresaw and anticipated all the great discoveries which have since been made in those countries. A thousand points in the history of ancient nations, which have hitherto been either overlooked or accepted without inquiry, are here treated with sound criticism and placed in their true light.

Niebuhr's Lectures on Ancient Ethnography and Geography. Comprising Greece and her Colonies, Italy, the Islands of the Mediterranean, Spain, Gaul, Britain, Northern Africa, and Phœnicia. Translated from the German by DR. LEONHARD SCHMITZ, F.R.S.E., Rector of the High School of Edinburgh, with additions and corrections from his own Notes. Two Vols. 8vo, 1*l.* 1*s.* cloth.

A History of Rome; from the Earliest Times to the Death of COMMODUS, A.D. 192. By Dr. L. SCHMITZ, Rector of the High School of Edinburgh, Editor of "Niebuhr's Lectures." New Edition. With 100 Illustrations on Wood. One thick Vol. 12mo, 7*s.* 6*d.* cloth.

Questions on Schmitz's History of Rome. By JOHN ROBSON, B.A. 12mo, 2*s.* cloth.

A History of Greece. With Supplementary Chapters on the Literature, Art, and Domestic Manners of the Greeks. By William Smith, LL.D., Editor of the Dictionaries of "Greek and Roman Antiquities," "Biography," &c. Woodcuts and Maps. Post 8vo, 7*s.* 6*d.* cloth.

"A good plan capitally executed, is the characteristic of Dr. Smith's introductory History of Greece."—*Spectator.*

The Book of Almanacs. With Index, by which the Almanac belonging to any year preceding A.D. 2000 can be found; with means of finding New and Full Moons from B.C. 2000 to A.D. 2000. By AUGUSTUS DE MORGAN, Professor of Mathematics in University College, London. Demy 8vo, oblong, 5*s.* cloth.

"This is quite a novelty in chronological literature. It is an *universal almanac*—universal, that is, as respects time, past, present, and future. The main object of it is, as the compiler states, to supply the place of an old almanac, which is never at hand when wanted; of the older almanac, which never was at hand; and of the universal almanac in every shape! A more useful chronological handbook could scarcely be conceived. It will save an immensity of calculation, and is in many other respects invaluable as a chronological guide and instructor."—*Oxford Herald.*

A Numismatic Manual; or Guide to the Collection and Study of Greek, Roman, and English Coins. Illustrated by Engravings of many hundred types, by means of which even imperfect and obliterated pieces may be easily deciphered. By J. Y. AKERMAN, F.S.A. 8vo, 21*s.* cloth.

POETRY.

DISCOVERY. A POEM. By Edward Aldam Leatham, M.A. Foolscap 8vo, 2*s.* 6*d.* cloth.

"His execution is finished and of a good school."—*Spectator.*

"Mr. Leatham's style is vigorous, his lines are musical, and his versification is correct. * * His peroration is truly eloquent."—*Britannia.*

Love in the Moon; A POEM. With Remarks on that Luminary. By Patrick Scott, Author of "Lelio." Foolscap 4to, 5*s.* 6*d.* cloth gilt.

Poetical Works of John Keats. Royal 8vo, sewed, 2*s.*

A Collection of Poetry for the Practice of Elocution. Made for the use of the Ladies' College, Bedford Square. By Professor F. W. Newman. Foolscap 8vo, 2*s.* 6*d.*

The Georgics of Virgil. Translated into Verse by the Rev. W. H. Bathurst, M.A., Rector of Barwick-in-Elmet. Foolscap 8vo, 4*s.* 6*d.* cloth.

MISCELLANEOUS.

GUESSES at Truth. By Two Brothers. Cheaper Edition. With an Index. 2 vols. Foolscap 8vo. 10*s.*, cloth-lettered.

Business as it is and as it might be. By Joseph Lyndall. Crown 8vo, 1*s.* sewed, 1*s.* 6*d.* cloth.

⁂ This Work obtained the Prize of Fifty Guineas offered by the Young Men's Christian Association for the best Essay on "The Evils of the Present System of Business, and the Difficulties they Present to the Attainment and Development of Personal Piety, with Suggestions for their Removal."

Christian Philosophy; or, an Attempt to Display the Evidence and Excellence of Revealed Religion by its Internal Testimony. By Vicesimus Knox, D.D., late Fellow of St. John's College, Oxford; and Master of Tunbridge School. Foolscap 8vo., 2*s.* 6*d.*, cloth.

Suggestions on Female Education. Two Introductory Lectures on English Literature and Moral Philosophy, delivered in the Ladies' College, Bedford Square, London. By A. J. Scott, A.M., Principal of Owen's College, Manchester, late Professor of the English Language and Literature in University College, London. Foolscap 8vo, 1*s.* 6*d.*

Mr. Frere's Works on Prophecy.

Brief Interpretation of the Apocalypse. 8vo, 3*s.* 6*d.* cloth.

General Structure of the Apocalypse, chiefly relating to the Individual Antichrist of the Last Days. 8vo, 2*s.*

Three Letters on the Prophecies. 8vo, 2*s.*

Eight Letters on the Prophecies; viz. on the Seventh Vial; the Civil and Ecclesiastical Periods; and on the Type of Jericho. 8vo, 2*s.* 6*d.*

Great Continental Revolution, marking the expiration of the "Times of the Gentiles." 8vo, 2*s.* 6*d.*

STEAM NAVIGATION AND RAILWAYS.

THE Steam Engine, Steam Navigation, Roads, and Railways, EXPLAINED AND ILLUSTRATED. A New and Cheaper Edition, revised and completed to the present time. By Dionysius Lardner, D.C.L., formerly Professor of Natural Philosophy and Astronomy in University College, London. One Vol. 12mo, Illustrated with Wood Engravings, 8*s.* 6*d.* cloth.

NATURAL PHILOSOPHY AND ASTRONOMY.

POPULAR Astronomy. By DIONYSIUS LARDNER, D.C.L., containing,—How to observe the Heavens; Latitude and Longitude; The Earth; The Sun; The Moon; The Planets, are they inhabited? The New Planets; Leverrier and Adams' Planet; Lunar Influences; The Tides; Lunar Influences and the Stellar Universe. From the *Museum of Science and Art.* 1 volume, with 119 Engravings. 12mo, 2*s.* 6*d.* cloth lettered.

Common Things Explained. By DIONYSIUS LARDNER, D.C.L., containing, —Air; Earth; Fire; Water; Time; The Almanac; Clocks and Watches; Spectacles; Colour; Kaleidoscope; Pumps. From the *Museum of Science and Art.* 1 volume with 114 Engravings. 12mo, 2*s.* 6*d.* cloth lettered.

The Electric Telegraph Popularised. With 100 Illustrations. By DIONYSIUS LARDNER, D.C.L. From the "Museum of Science and Art." 12mo, 2*s.* cloth.

"The reader will find the most complete and intelligible description of Telegraphic Apparatus in Dr. Lardner's admirable chapters on the subject."—*North British Review.*

Familiar Letters on the Physics of the Earth. By H. BUFF, Professor of Physics in the University of Giessen. Edited by Dr. A. W. HOFMANN, Professor in the Royal College of Chemistry, London. Fcap. 8vo, 5*s.*

Introduction.—Gravity and its Effects.—Tides.—Heat within the Earth.—Warm Springs.—Hot Springs and Jets of Steam.—Jets of Gas and Mud Volcanoes.—Volcanoes and Earthquakes.—Temperature of the Outermost Crust of the Earth.—Temperature of the Lowest Layer of the Atmosphere.—Lines of equal Heat.—Temperature of the Upper Layers of the Atmosphere.—The Snow Limits. —Glaciers.—Temperature of the Waters, and their Influence on Climate.—Currents of the Sea.—Winds.—Moisture of the Air and Atmospheric Precipitation. —Electricity of the Air, Lightning, and Thunder.

An Elementary Treatise on Mechanics, for the Use of Junior University Students. By RICHARD POTTER, A.M., Professor of Natural Philosophy in University College, London. Third Edition, 8vo, with numerous Diagrams, 8*s.* 6*d.* cloth.

An Elementary Treatise on Optics, PART I. By RICHARD POTTER, A.M. Second Edition, 8vo, corrected, with numerous Diagrams, 9*s.* 6*d.* cloth.

An Elementary Treatise on Optics, PART II., Containing the Higher Propositions. By RICHARD POTTER, A.M. 8vo, with numerous Diagrams, 12*s.* 6*d.*

Twelve Planispheres, forming a Guide to the Stars for every Night in the Year, with an Introduction. 8vo, 6*s.* 6*d.* cloth.

Ecliptical Charts, Hours, 1, 2, 3, 4, 5, 7, 9, 10, 11, 13, 14, 19, and 20, taken at the Observatory, Regent's Park, under the direction of GEORGE BISHOP, Esq., F.R.S., &c. 2*s.* 6*d.* each.

Astronomical Observations, taken at the Observatory, Regent's Park, during the Years 1839—1851, under the direction of GEORGE BISHOP, Esq., F.R.S., &c. 4to, 12*s.* 6*d.*

Mr. Bishop's Synoptical Table of the Elements of the Minor Planets, between Mars and Jupiter, as known at the beginning of 1855, with the particulars relating to their discovery, &c. Arranged at the Observatory, Regent's Park. On a Card.

DR. LARDNER'S
MUSEUM OF SCIENCE AND ART.

A Miscellany of

INSTRUCTIVE AND AMUSING TRACTS ON THE PHYSICAL SCIENCES, AND ON THEIR APPLICATION TO THE USES OF LIFE.

ILLUSTRATED BY ENGRAVINGS ON WOOD.

DOUBLE VOLUMES.

Volumes 1 *to* 6 *may now be had, strongly bound,* 2 *Volumes in* 1 *with Indexes, cloth lettered, price* 8*s.* 6*d. each double volume.*

"'Dr. Lardner's Museum,' one of the few works of the kind which can be recommended as at once popular and accurate."—*Sir David Brewster.*

Contents of Vols. I. and II. (double), 8s. 6d. cloth.

VOL. I., *price* 1*s.* 6*d.*, *in handsome boards.*

PART I., price 5*d.*

1. The Planets; Are they Inhabited Globes?
2. Weather Prognostics.
3. The Planets. Chap. II.
4. Popular Fallacies in Questions of Physical Science.

PART II., price 5*d.*

5. Latitudes and Longitudes.
6. The Planets. Chap. III.
7. Lunar Influences.
8. Meteoric Stones and Shooting Stars. Chap. I.

PART III., price 6*d.*

9. Railway Accidents. Chap. I.
10. The Planets. Chap. IV.
11. Meteoric Stones and Shooting Stars. Chap. II.
12. Railway Accidents. Chap. II.
13. Light.

VOL. II., *price* 1*s.* 6*d.*, *in handsome boards.*

PART IV., price 5*d.*

14. Common Things.—Air.
15. Locomotion in the United States. Chap. I.
16. Cometary Influences. Chap. I.
17. Locomotion in the United States. Chap. II.

PART V., price 5*d.*

18. Common Things.—Water.
19. The Potter's Art. Chap. I.
20. Locomotion in the United States. Chap. III.
21. The Potter's Art. Chap. II.

PART VI., price 6*d.*

22. Common Things.—Fire.
23. The Potter's Art. Chap. III.
24. Cometary Influences. Chap. II.
25. The Potter's Art. Chap. IV.
26. The Potter's Art. Chap. V.

Contents of Vols. III. and IV. (double), 8s. 6d. cloth.

VOL. III., *price* 1*s.* 6*d.*, *in handsome boards.*

PART VII., price 5*d.*

27. Locomotion and Transport, their Influence and Progress. Chap. I.
28. The Moon.
29. Common Things.—The Earth.
30. Locomotion and Transport, their Influence and Progress. Chap. II.

PART VIII., price 5*d.*

31. The Electric Telegraph. Chap. I.
32. Terrestrial Heat. Chap. I.
33. The Electric Telegraph. Chap. II.
34. The Sun.

PART IX., price 6*d.*

35. The Electric Telegraph. Chap. III.
36. Terrestrial Heat. Chap. II.
37. The Electric Telegraph. Chap. IV.
38. The Electric Telegraph. Chap. V.
39. The Electric Telegraph. Chap. VI.

VOL. IV., *price* 1*s.* 6*d.*, *in handsome boards.*

PART X., price 5*d.*

40. Earthquakes and Volcanoes. Chap. I.
41. The Electric Telegraph. Chap. VII.
42. The Electric Telegraph. Chap. VIII.
43. The Electric Telegraph. Chap. IX.

PART XI., price 5*d.*

44. Barometer, Safety Lamp, and Whitworth's Micrometric Apparatus.
45. The Electric Telegraph. Chap. X.
46. Earthquakes and Volcanoes. Chap. II.
47. The Electric Telegraph. Chap. XI.

PART XII., price 6*d.*

48. Steam.
49. The Electric Telegraph. Chap. XII.
50. The Electric Telegraph. Chap. XIII.
51. The Electric Telegraph. Chap. XIV.
52. The Electric Telegraph. Chap. XV.

DR. LARDNER'S MUSEUM (*Continued*):—

Contents of Vols. V. and VI. (double), 3s. 6d. cloth.

VOL. V., *price* 1s, 6d.,

PART XIII., price 5*d.*

53. The Steam Engine. Chap. I.
54. The Eye. Chap. I.
55. The Atmosphere.
56. Time. Chap. I.

Part XIV., price 5*d.*

57. The Steam Engine. Chap. II.
58. Common Things. Time. Chap. II.
59. The Eye. Chap. II.
60. Common Things. Pumps.

Part XV., price 6*d.*

61. The Steam Engine. Chap. III.
62. Common Things. Time. Chap. III.
63. The Eye. Chap. III.
64. Common Things. Time. Chap. IV.
65. Common Things. Spectacles—The Kaleidoscope.

VOL. VI., *price* 1s. 6d.,

PART XVI., price 5*d.*

66. Clocks and Watches. Chap. I.
67. Microscopic Drawing and Engraving. Chap. I.
68. Locomotive. Chap. I.
69. Microscopic Drawing and Engraving. Chap. II.

PART XVII., price 5*d.*

70. Clocks and Watches. Chap. II.
71. Microscopic Drawing and Engraving. Chap. III.
72. Locomotive. Chap. II.
73. Microscopic Drawing and Engraving. Chap. IV.

PART XVIII., price 6*d.*

74. Clocks and Watches. Chap. III.
75. Thermometer.
76. New Planets.—Leverrier and Adams' Planet.
77. Leverrier and Adams' Planet, concluded.
78. Magnitude and Minuteness.

Contents of Vols. VII. and VIII. (double), 3s. 6d. cloth.

VOL. VII., *price* 1s. 6d.,

PART XIX. price 5*d.*

79. Common Things. The Almanack. Chap. I.
80. Optical Images. Chap. I.
81. Common Things. The Almanack. Chap. II.
82. Optical Images. Chap. II.

PART XX. price 5*d.*

83. How to Observe the Heavens. Chap. I.
84. Optical Images. Chap. III. Common Things. The Looking-Glass.
85. Common Things. The Almanack. Chap. III.
86. How to Observe the Heavens. Chap. II. Stellar Universe. Chap. I.

PART XXI. price 6*d.*

87. The Tides.
88. Stellar Universe. Chap. II.
89. Common Things. The Almanack. Chap. IV. Colour. Chap. I.
90. Stellar Universe. Chap. III.
91. Colour. Chap. II.

VOL. VIII., *price* 1s. 6d.,

PART XXII. price 5*d.*

92. Common Things. Man. Chap. I.
93. The Stellar Universe. Chap. IV.
94. Magnifying glasses.
95. Common Things. Man. Chap. II.

PART XXIII. price 5*d.*

96. Instinct and Intelligence. Chap. I.
97. The Stellar Universe. Chap. V.
98. Common Things. Man. Chap. III.
99. Instinct and Intelligence. Chap. II.

PART XXIV. price 6*d.*

100. Instinct and Intelligence. Chap. III.
101. The Solar Microscope.—The Camera Lucida.
102. The Stellar Universe. Chap. VI.
103. Instinct and Intelligence. Chap. IV.
104. The Magic Lantern.—The Camera Obscura.

⁂ *Continued in Weekly Numbers at* 1*d.; Monthly Parts at* 5*d.; Quarterly Volumes at* 1*s.* 6*d.*, *and Half Yearly Volumes at* 3*s.* 6*d.*

First Book of Natural Philosophy; or, an Introduction to the Study of Statics, Dynamics, Hydrostatics, and Optics, with numerous examples. By SAMUEL NEWTH, M.A., Fellow of University College, London. 12mo, 3*s.* 6*d.*

Elements of Mechanics and Hydrostatics. By SAMUEL NEWTH, M.A. Second Edition, small 8vo, 7*s.* 6*d.* cloth.

A Handbook of Natural Philosophy. By Dionysius Lardner, D.C.L., Formerly Professor of Natural Philosophy and Astronomy in University College, London. A New Edition, revised and greatly enlarged, with several hundred additional Illustrations. To appear in 18 Monthly Parts, at 1*s.*, and in 4 Volumes (one every two months), 5*s.* each, cloth lettered. Being a series of Treatises composed in a popular and generally intelligible style, independently of the language and symbols of Mathematics.

Mechanics. One Volume. *Ready.*
Hydrostatics, Pneumatics, and Heat. One Volume. *Ready.*
Optics. One Volume.
Electricity, Magnetism, Acoustics, and Meteorology. One Volume.

Parts I. *to* III., *each* 1*s.*, *and* MECHANICS, 1 *Vol.* 5*s.*, *cloth;* HYDROSTATICS, PNEUMATICS AND HEAT, 1 *Vol.* 5*s.* *cloth, are now ready.*

Dr. Lardner's Handbook of Astronomy. From the "Handbook of Natural Philosophy and Astronomy." 37 Plates and 200 Woodcuts. Large 12mo, 16*s.* 6*d.* cloth.

Lardner's Handbook of Natural Philosophy and Astronomy.

The following Volumes of the First Edition are still on Sale.

SECOND COURSE, One Vol., 8*s.* 6*d.*, contains:—Heat; Common Electricity; Magnetism; Voltaic Electricity.

THIRD COURSE, One Vol., 16*s.* 6*d.*, contains:—Astronomy and Meteorology. With 37 Plates and 200 Woodcuts.

⁂ *Either volume may be purchased separately.*

MATHEMATICS, &c.

ELEMENTS of Arithmetic. By Augustus De Morgan, Professor of Mathematics in University College, London. Fifth Edition, with Eleven Appendixes, Royal 12mo, 5*s.* cloth.

De Morgan's Trigonometry and Double Algebra. Royal 12mo, 7*s.* 6*d.* cloth.

Barlow's Tables of Squares, Cubes, Square Roots, Cube Roots, AND RECIPROCALS, up to 10,000. Stereotype Edition, examined and corrected. Under the superintendence of the Society for the Diffusion of Useful Knowledge. Royal 12mo, cloth, 8*s.*

Arithmetical Books and Authors. From the Invention of Printing to the present time; being Brief Notices of a large Number of Works drawn up from actual inspection. By Augustus De Morgan, Professor of Mathematics in University College, London. Cheap issue. Royal 12mo, 2*s.* 6*d.* cloth.

A Course of Arithmetic as Taught in the Pestalozzian School, WORKSOP. By J. L. Ellenberger. 12mo, 5*s.* cloth.

The First Book of Euclid Explained to Beginners. By C. P. Mason, B.A., Fellow of University College, and Principal of Denmark Hill Grammar School. Fcap. 8vo, 1*s.* 9*d.* cloth.

Reiner's Lessons on Form; or, an Introduction to Geometry, as given in a Pestalozzian School, Cheam, Surrey. 12mo, with numerous Diagrams, 3*s.* 6*d.* cloth.

A First Book on Plane Trigonometry. Geometrical Trigonometry, and its applications to Surveying, with numerous Examples. For the use of Schools. By G. W. Hemming, M.A., Fellow of St. John's College, Cambridge, and Author of a Treatise on the "Differential and Integral Calculus." With Diagrams, 12mo, cloth limp, 1*s.* 6*d.*

Ritchie's Principles of Geometry, familiarly Illustrated, and applied to a variety of useful purposes. Designed for the Instruction of Young Persons. Second Edition, revised and enlarged, 12mo, with 150 Woodcuts, 1*s.* 6*d.*

Tables of Logarithms, Common and Trigonometrical, to Five PLACES. Under the Superintendence of the Society for the Diffusion of Useful Knowledge. Fcap. 8vo, cloth limp, 1*s*. 6*d*.

Lessons on Number, as given at the Pestalozzian School, Cheam, Surrey. By CHARLES REINER. The Master's Manual. New Edition. 12mo, cloth, 5*s*. The Scholar's Praxis. 12mo, 2*s*. bound.

GREEK.

THE Anabasis of Xenophon. Expressly for Schools. With Notes, a Geographical and Biographical Index, and a Map. By J. T. V. HARDY, B.A., Principal of Huddersfield College; and ERNEST ADAMS, Classical Master in University College School. 12mo, 4*s*. 6*d*. cloth.

Lexicon to Aeschylus. Containing a Critical Explanation of the more Difficult Passages in the Seven Tragedies. By the Rev. W. LINWOOD, A.M., M.R.A.S. Second Edition. Revised. 8vo, 12*s*. cloth.

New Greek Delectus; Being Sentences for Translation from Greek into English, and English into Greek; arranged in a Systematic Progression. By Dr. RAPHAEL KUHNER. Translated and Edited from the German, by Dr. ALEXANDER ALLEN. Third Edition, revised. 12mo, 4*s*. cloth.

Four Gospels in Greek. For the use of Schools. Fcap. 8vo. cloth limp, 1*s*. 6*d*. This part of the Greek Testament is printed separately for the use of Students beginning to learn Greek, the Evangelists being more generally read than the rest of the Testament.

London Greek Grammar. Designed to exhibit, in small compass, the Elements of the Greek Language. Edited by a GRADUATE of the University of Oxford. Fifth Edition. 12mo, cloth limp, 1*s*. 6*d*.

Greek Testament. GRIESBACH'S TEXT, with the various readings of MILL and SCHOLZ. Second Edition, revised. Fcap. 8vo, cloth, 6*s*. 6*d*.; morocco, 12*s*. 6*d*.

Plato. The Apology of SOCRATES, CRITO, and part of the PHAEDO, with English Notes, a Life of Socrates, &c. Edited by Dr. W. SMITH. Second Edition. 12mo, cloth, 5*s*.

Robson's Constructive Greek Exercises. 12mo, cloth, 7*s*. 6*d*.

⁂ This Work, which was originally intended to be a new edition of "Allen's Constructive Greek Exercises," will take the place of that book. The general principles of both are identical.

Introduction to the Art of Composing Greek Iambics, in Imitation of the Greek Tragedians. Designed for the use of Schools. By the Rev. CHARLES TAYLER. 12mo, 2*s*. 6*d*.

What is the Power of the Greek Article; and how may it be expressed in the English Version of the New Testament? By JOHN TAYLOR. 8vo, 2*s*. 6*d*.

LATIN.

NEW Latin Delectus; being Sentences for Translation from Latin into English, and English into Latin; arranged in a Systematic Progression, on the plan of the Greek Delectus. By Dr. ALEXANDER ALLEN. Third Edition, 12mo, 4*s*. cloth.

New Latin Reading-Book; Short Sentences, Easy Narrations, and Descriptions, from Cæsar's Gallic War, arranged in Systematic Progression. With a Dictionary. Second Edition, revised. 12mo, 2*s*. 6*d*. cloth.

Constructive Latin Exercises, for teaching the Elements of the Language on a System of Analysis and Synthesis; with Latin Reading Lessons, and copious Vocabularies. By JOHN ROBSON, B.A., late Assistant Master in University College School. Third Edition, thoroughly revised. 12mo, 4*s*. 6*d*. cloth.

London Latin Grammar; including the Eton Syntax and Prosody in English, accompanied with Notes. Edited by a GRADUATE of the University of Oxford. Fifteenth Edition. 12mo, 1*s*. 6*d*. cloth limp.

First Latin Reading Lessons; with complete Vocabularies. Intended as an Introduction to Cæsar. By JOHN ROBSON, B.A., Assistant Master in University College School. 12mo, 2*s*. 6*d*. cloth.

The Principal Roots of the Latin Language, simplified by a display of their Incorporation into the English Tongue; with copious Notes. By HENRY HALL. Fifth Edition. 12mo, 1*s*. 6*d*. cloth limp.

The Germania of Tacitus. With Ethnological Dissertations and Notes. By Dr. R. G. LATHAM. Author of the "English Language," &c. With a Map. Demy 8vo, 12*s*. 6*d*.

Tacitus, Germania, Agricola, and First Book of the Annals. With English Notes and BOTTIGER'S Remarks on the style of TACITUS. Third Edition revised and much improved. Edited by Dr. W. SMITH. 12mo, 5*s*. cloth.

Caesar for Beginners. Latin and English; with the Original Text at the end. 12mo, 3*s*. 6*d*. cloth.

Mythology for Versification; or, a Brief Sketch of the Fables of the Ancients, prepared to be rendered into Latin verse. By the late Rev. F. HODGSON, M.A. (Provost of Eton). New Edition. 12mo, 3*s*. bound. KEY to Ditto. 8vo, 7*s*.

Select Portions of Sacred History, conveyed in sense for Latin Verses. By the late Rev. F. HODGSON, M.A. (Provost of Eton). Third Edition. 12mo, 3*s*. 6*d*. cloth. KEY to Ditto. Royal 8vo, 10*s*. 6*d*. cloth.

Sacred Lyrics; or, Extracts from the Prophetical and other Scriptures of the Old Testament; adapted to Latin Versification in the principal Metres of HORACE. By the late Rev. F. HODGSON, M.A. (Provost of Eton). 12mo, 6*s*. 6*d*. cloth. KEY to Ditto. 8vo, 12*s*. cloth.

Latin Authors. Selected for the use of Schools; containing portions of Phædrus, Ovid's Metamorphoses, Virgil's Æneid, Cæsar and Tacitus. 12mo, 1*s*. 6*d*. cloth.

HEBREW.

GRAMMAR of the Hebrew Language. By HYMAN HURWITZ, late Professor of Hebrew in University College, London. Fourth Edition, revised and enlarged. 8vo, 13*s*. cloth. Or in Two Parts, sold separately:—ELEMENTS, 4*s*. 6*d*. cloth; ETYMOLOGY and SYNTAX, 9*s*. cloth.

Book of Genesis in English Hebrew; accompanied by an Interlinear Translation, substantially the same as the authorised English version; Philological Notes, and a Grammatical Introduction. By W. GREENFIELD, M.R.A.S. Fourth Edition. Cheap Issue. 8vo, 4*s*. 6*d*. cloth. With the original Text in Hebrew characters at the end. 8vo, 6*s*. 6*d*. cloth.

MAPS.

TEACHING Maps:—I. RIVERS AND MOUNTAINS, of England, Wales, and Part of Scotland. 6*d*. II.—TOWNS of Ditto. 6*d*.

Projections. Three Maps. MERCATOR. EUROPE. BRITISH ISLES. Stitched in a Cover, 1*s*. Single Maps, 4*d*. each.

Projections; with Outline of Country. Three Maps stitched in a Cover, 1*s*. Single Maps, 4*d*. each.

ENGLISH.

THE English Language. By Dr. R. G. LATHAM, F.R.S., late Fellow of King's College, Cambridge. Fourth Edition, greatly enlarged. 2 Vols. 8vo. 1*l*. 8*s*.

A Handbook of the English Language. By Dr. R. G. LATHAM, F.R.S. Second Edition, revised and much improved. Crown 8vo, 7*s*. 6*d*. cloth.

An English Grammar for the Use of Schools. By Dr. R. G. LATHAM, F.R.S., late Fellow of King's College, Cambridge. Sixth Edition. 12mo, 4*s*. 6*d*. cloth.

Elements of English Grammar, for the Use of Ladies' Schools. By Dr. R. G. LATHAM, F.R.S. Fcap. 8vo, 1*s*. 6*d*. cloth.

Elements of English Grammar, for Commercial Schools. By Dr. R. G. LATHAM, F.R.S. Fcap. 8vo, 1*s*. 6*d*. cloth.

History and Etymology of English Grammar, for the Use of CLASSICAL SCHOOLS. By Dr. R. G. LATHAM, F.R.S. Fcap. 8vo, 1*s*. 6*d*. cloth.

First Outlines of Logic, applied to Grammar and Etymology. By Dr. R. G. LATHAM. 12mo, 1*s*. 6*d*. cloth.

New English Spelling Book. By the Rev. GORHAM D. ABBOTT. Second Edition, with Reading Lessons. 12mo, sewed, 6*d*.

First English Reader. By the Rev. G. D. ABBOTT. 12mo, with Illustrations. 1*s*. cloth limp.

Second English Reader. By the Rev. G. D. ABBOTT. 12mo, 1*s*. 6*d*. cloth limp.

FRENCH.

MERLET'S French Grammar. By P. F. MERLET, Professor of French in University College, London. New Edition. 12mo, 5*s*. 6*d*. bound. Or, sold in two Parts: PRONUNCIATION and ACCIDENCE, 3*s*. 6*d*.; SYNTAX, 3*s*. 6*d*. (KEY, New Edition, 3*s*. 6*d*.)

Merlet's Traducteur; Or, HISTORICAL, DRAMATIC, and MISCELLANEOUS SELECTIONS from the best FRENCH WRITERS; accompanied by Explanatory Notes; a selection of Idioms, &c. New Edition. 12mo, 5*s*. 6*d*. bound.

Merlet's Dictionary of the Difficulties of the French Language; containing Explanations of every Grammatical Difficulty; Synonymes explained in a concise manner; Versification; Etymological Vocabulary; Free Exercises, with Notes; Mercantile Expressions, Phrases, and Letters; Elements of French Composition. A new and enlarged Edition. 12mo, 6*s*. 6*d*. bound.

Merlet's French Synonymes; explained in Alphabetical Order, with Copious Examples. (From the "DICTIONARY OF DIFFICULTIES.") 12mo, 2*s*. 6*d*. cloth.

Stories from French Writers. Interlinear (from Merlet's "Traducteur".) 12mo, 2*s*.

GERMAN.

The Adventures of Ulysses: a German Reading Book; with a short Grammar and a Vocabulary. By PAUL HIRSCH. Twenty-four Woodcuts. 12mo, 6*s*. cloth.

Separately,

A Short Grammar of the German Language. 12mo, cloth, 2*s*.

ITALIAN.

First Italian Course; Being a Practical and Easy Method of Learning the Elements of the Italian Language. By W. BROWNING SMITH, M.A., Second Classical Master of the City of London School. Royal 18mo, cloth, 3*s*. 6*d*.

Panizzi's Italian Grammar. 12mo, cloth limp, 1*s*. 6*d*.

INTERLINEAR TRANSLATIONS.

Cheap Issue, at 1s. 6d. per volume.

LOCKE'S System of Classical Instruction, restoring the Method of Teaching formerly practised in all Public Schools. The Series consists of the following Interlinear Translations with the Original Text, in which the quantity of the doubtful Vowels is denoted; critical and explanatory Notes, &c.

⁂ By means of these Works, that excellent system of Tuition is effectually restored which was established by Dean Colet, Erasmus, and Lily, at the foundation of St. Paul's School, and was then enjoined by authority of the State, to be adopted in all other Public Seminaries of learning throughout the kingdom. Each Volume, 1*s.* 6*d.*

LATIN.	GREEK.
1. Phædrus's Fables of Æsop.	1. Lucian's Dialogues. Selections.
2. Ovid's Metamorphoses. Book I.	2. The Odes of Anacreon.
3. Virgil's Æneid. Book I.	3. Homer's Iliad. Book I.
4. Parsing Lessons to Virgil.	4. Parsing Lessons to Homer.
5. Cæsar's Invasion of Britain.	5. Xenophon's Memorabilia. Part I.
	6. Herodotus's Histories. Selections.

FRENCH.—Sismondi; the Battles of Cressy and Poictiers.

GERMAN.—Stories from German Writers.

⁂ A Second Edition of the Essay, explanatory of the System, with an Outline of the Method of Study, is published. 12mo, sewed, price 6*d.*

ANIMAL MAGNETISM.

BARON Von Reichenbach's Researches on Magnetism, Elec- TRICITY, HEAT, LIGHT, CRYSTALLISATION, AND CHEMICAL ATTRACTION, IN THEIR RELATION TO THE VITAL FORCE. Translated and Edited (at the express desire of the Author) by Dr. Gregory, of the University of Edinburgh. Cheap Issue. One Volume, 8vo, 6*s.* 6*d.* cloth.

"The merits of this remarkable volume are great. The painstaking, conscientious, cautious, ingenious,—we had almost said the religious, and certainly the self-possessed enthusiasm with which the experimental clue is followed from turn to turn of the labyrinth, is surpassed by nothing of the same sort in the whole range of contemporary science."—*North British Review.*

ANATOMY, MEDICINE, &c.

DR. Quain's Anatomy. Edited by Dr. Sharpey and Mr. Quain, Professors of Anatomy and Physiology in University College, London. Fifth Edition. Complete in Two Volumes, 8vo. Illustrated by four hundred Engravings on Wood. Price 2*l.*

Demonstrations of Anatomy. A Guide to the Dissection of the Human Body. By George Viner Ellis, Professor of Anatomy in University College, London. Third Edition. Small 8vo. 12*s.* 6*d.* cloth.

The Essentials of Materia Medica, Therapeutics, and the PHARMACOPŒIAS. For the use of Students and Practitioners. By Alfred Baring Garrod, M.D., Professor of Materia Medica and Therapeutics in University College, London. Fcp. 8vo. 6*s.* 6*d.*

Lectures on the Principles and Practice of Midwifery. By Edward Wm. Murphy, A.M., M.D., Professor of Midwifery in University College, London. One Volume, 8vo, many Illustrations, 16*s.*

"The work will take rank among the best treatises on the obstetric art. By this work, Dr. Murphy has placed his reputation and his fame on a solid and durable foundation."—*Dublin Medical Press.*

A Handbook of Physiology. By WILLIAM SENHOUSE KIRKES, M.D., Demonstrator of Morbid Anatomy at St. Bartholomew's Hospital. Assisted by JAMES PAGET, Lecturer on General Anatomy and Physiology at St. Bartholomew's Hospital. Second Edition. One Volume 12mo, with Illustrations. 12*s.* 6*d.*

On Pain After Food; its Causes and Treatment. By EDWARD BALLARD, M.D., Lond., Lecturer on the Practice of Medicine at the School of Medicine adjoining St. George's Hospital. One vol. 4*s.* 6*d.* cloth.

Physical Diagnosis of the Diseases of the Abdomen. By EDWARD BALLARD, M.D., Late Medical Tutor in University College, London. Large 12mo, 7*s.* 6*d.* cloth.

"The profession is much indebted to Dr. Ballard for this unpretending little volume, which, we feel certain, if carefully studied, will accomplish its object of removing many of the difficulties at present surrounding the diagnosis of abdominal diseases."—*Lancet.*

A Practical Treatise on Diseases of the Heart and Lungs, their Symptoms and Treatment, and the Principles of Physical Diagnosis. By W. H. WALSHE, M.D., Professor of the Principles and Practice of Medicine and Clinical Medicine in University College, London; Physician to University College Hospital, and Consulting Physician to the Hospital for Consumption and Diseases of the Chest. A new and considerably enlarged edition. One Volume, 12*s.* 6*d.* cloth.

"This work is what its name indicates it to be—eminently practical. That it will add largely to the already great reputation of its author, no question can be entertained. It is far in advance of any other Treatise on Diseases of the Chest, either in this or any other country. Every page—we were about to say every line—contains a fact, often new, and *always resting on the Author's own observations.* Cases are quoted to prove every new statement, and to support every argument adduced in opposition to others. To the practitioner, the clinical teacher, and to the student, this work will prove alike invaluable."—*Medical Times.*

The Nature and Treatment of Cancer. By W. H. WALSHE, M.D., Professor of Medicine in University College, Physician to University College Hospital, and Consulting Physician to the Hospital for Consumption and Diseases of the Chest. One Volume, 8vo, with Illustrations. Cheap Issue, 6*s.* 6*d.*

The Diseases of the Rectum. By RICHARD QUAIN, F.R.S., Professor of Clinical Surgery in University College, and Surgeon to University College Hospital. With Lithographic Plates. Second edition enlarged. Post 8vo. 7*s.* 6*d.* cloth.

"This Treatise is eminently of a practical character, and contains much original and valuable matter. It is not indeed a literary compilation, but rather an exposition of the author's opinions and practice in those diseases."—*Association Journal.*

The Science and Art of Surgery. Being a Treatise on Surgical Injuries, Diseases, and Operations. By JOHN ERICHSEN, Professor of Surgery in University College, and Surgeon to University College Hospital. 250 Wood Engravings. 8vo. 1*l.* 5*s.*

"The aim of Mr. Erichsen appears to be, to improve upon the plan of Samuel Cooper; and by connecting in one volume the science and art of Surgery, to supply the student with a text-book and the practitioner with a work of reference, in which scientific principles and practical details are alike included.

"It must raise the character of the author, and reflect great credit upon the College in which he is Professor, and we can cordially recommend it as a work of reference, both to students and practitioners."—*Medical Times.*

The Microscopic Anatomy of the Human Body in Health AND DISEASE. Illustrated with numerous Drawings in Colour. By ARTHUR HILL HASSALL, M.B., Fellow of the Linnæan Society, Member of the Royal College of Surgeons, &c. &c. Two Vols. 8vo, 2*l.* 5*s.*

Hassall's History of the British Freshwater Algæ, including Descriptions of the Desmideæ and Diatomaceæ. With upwards of 100 Plates, illustrating the various species. Two Vols. 8vo, 2*l.* 5*s.*

Morton's Surgical Anatomy of the Principal Regions. Completed by Mr. Cadge, late Assistant Surgeon, University College Hospital. Twenty-five Lithographic Illustrations Coloured, and Twenty-five Woodcuts. Royal 8vo, 21*s.* cloth lettered.

"The work thus completed constitutes a useful guide to the student, and remembrancer to the practitioner. We can speak very favourably of the general execution of the work. The coloured lithographs are, for the most part, well drawn, and faithfully represent the broad features of the several parts. The woodcuts are well engraved, and very clearly exhibit the points which they are intended to illustrate."—*Medical Gazette.*

A Series of Anatomical Plates in Lithography. Edited by Jones Quain, M.D., and Erasmus Wilson, F.R.S.

*** *A remarkably cheap issue is now on sale at the following low prices:—*

	To Subscribers. £	*s.*	*d.*	Former Price. £	*s.*	*d.*
THE COMPLETE WORK, in Two Volumes, Royal Folio, Half-bound Morocco	5	5	0	8	8	0
THE SAME, Full Coloured, Half-bound Morocco	8	8	0	14	0	0

The Work may also be purchased in separate portions, bound in Cloth and Lettered, as follows:—

		PLAIN.							COLOURED.					
		To Subscribers.			Former Price.				To Subscribers.			Former Price.		
		£	*s.*	*d.*	£	*s.*	*d.*		£	*s.*	*d.*	£	*s.*	*d.*
Muscles.	51 Plates	1	5	0	1	18	0	—	2	4	0	3	12	0
Vessels.	50 Plates	1	5	0	1	18	0	—	2	0	0	3	3	0
Nerves.	38 Plates	1	1	0	1	10	0	—	1	14	0	2	16	0
Viscera.	32 Plates	0	17	0	1	5	0	—	1	10	0	2	8	0
Bones and Ligaments.	30 Plates	0	17	0	1	5	0	—	1	0	0	1	11	6

*** *Proposals with full particulars may be had of the Publishers, by whom and by all Booksellers, Subscribers' names will be received.*

On Gravel, Calculus, and Gout; chiefly an Application of Professor Liebig's Physiology to the Prevention and Cure of those Diseases. By H. Bence Jones, M.D., F.R.S., Physician to St. George's Hospital. 8vo, 6*s.* cloth.

CHEMISTRY, &c.

PRINCIPLES of Agricultural Chemistry, with Special Reference to the late Researches made in England. By JUSTUS VON LIEBIG, Professor of Chemistry in the University of Munich. Small 8vo., 3*s.* 6*d.* cloth. *Just published.*

Familiar Letters on Chemistry. In its relations to Physiology, Dietetics, Agriculture, Commerce, and Political Economy. By Justus Von Liebig. A New and Cheap Edition, revised throughout, with many additional Letters. Complete in one Volume, Foolscap 8vo, price 6*s.* cloth.

Practical Pharmacy. The Arrangements, Apparatus, and Manipulations of the Pharmaceutical Shop and Laboratory. By Francis Mohr, Ph. D., and Theophilus Redwood, Professor of Chemistry and Pharmacy to the Pharmaceutical Society. 400 Engravings on Wood. 8vo, 6*s.* 6*d.* cloth.

Gregory's Handbook of Inorganic Chemistry. For the use of Students. By William Gregory, M.D., Professor of Chemistry in the University of Edinburgh. Third Edition, revised and enlarged. 12mo, 5*s.* 6*d.*

"A young man who has mastered these few and by no means closely printed pages, may venture to face any board of examiners on Chemistry, without fear of being posed by any fair question."—*Association Journal.*

Gregory's Handbook of Organic Chemistry; being a New and greatly Enlarged Edition of the "Outlines of Organic Chemistry, for the Use of Students." One volume, large 12mo, 9*s.* 6*d.* cloth.

Handbook of Organic Analysis. By Justus Liebig. Edited by Dr. Hofmann, Professor in the Royal College of Chemistry, London. Large 12mo. Illustrated by 85 Wood Engravings. 5s. cloth.

"The work now before us is a most valuable contribution to our knowledge on this most important subject. The style is lucid, and the processes are not only explained to the mind, but are made manifest to the eye by a profusion of beautiful illustrations."—*Medical Times.*

Handbook of Inorganic Analysis. By Friedrich Wöhler, M.D., Professor of Chemistry in the University of Gottingen. Translated and Edited by Dr. Hofmann, Professor in the Royal College of Chemistry, London. Large 12mo, 6s. 6d. cloth.

"Next to Rose of Berlin in the ranks of living analytic chemists, particularly in the inorganic department of the art, stands Friedrich Wöhler, who has in this book given us a compendium of inorganic analysis, illustrated by examples of the methods to be pursued in the examination of minerals, both of a simple and complex constitution, which, if followed out by the student with ordinary care and patience, and with some little practical instruction, will not fail to render him a thorough master of this division of chemical knowledge."—*Association Journal.*

Elements of Chemical Analysis, Qualitative, and Quantitative. By Edward Andrew Parnell, author of "Applied Chemistry; in Arts, Manufactures, and Domestic Economy." Second Edition, revised throughout, and enlarged by the addition of 200 pages. 8vo, Cheap Issue, 9s. cloth.

Animal Chemistry; or, Chemistry in its Applications to Physiology and Pathology. By Justus Liebig, M.D. Edited from the Author's Manuscript, by William Gregory, M.D. Third Edition, almost wholly re-written. 8vo, Part I. (the first half of the work) 6s. 6d. cloth.

Chemistry in its Application to Agriculture and Physiology. By Justus Liebig, M.D. Edited rom the Manuscript of the Author, by Lyon Playfair, Ph. D., and Wm. Gregory, M.D. Fourth Edition, revised. Cheap Issue. 8vo, 6s. 6d.

Dyeing and Calico Printing. By Edward Andrew Parnell, Author of "Elements of Chemical Analysis." (Reprinted from Parnell's "Applied Chemistry in Manufactures, Arts, and Domestic Economy, 1844.") With Illustrations. 8vo, 7s. cloth.

Outlines of the Course of Qualitative Analysis followed in the Giessen Laboratory. By Henry Will, Ph. D., Professor Extraordinary of Chemistry in the University of Giessen. With a Preface by Baron Liebig. 8vo, 6s., or with the Tables mounted on linen, 7s.

Turner's Elements of Chemistry. Edited by Professors Liebig and Gregory. Eighth Edition. 1 Vol. 8vo, 1l. 10s.

COMMON-PLACE BOOKS AND LITERARY DIARIES.

THE Private Diary. Arranged, Printed, and Ruled for receiving an account of every day's employment for the space of one year. With an Index and Appendix. Cheaper Edition. Post 8vo, strongly half-bound, 3s. 6d.

The Student's Journal. Formed on the plan of the "Private Diary." Cheaper Edition. Post 8vo, strongly half-bound, 3s. 6d.

The Literary Diary; or Complete Common-Place Book, with an Explanation and an Alphabet of Two Letters on a Leaf. Cheaper Edition. Post 4to, ruled throughout, and strongly half-bound, 8s. 6d.

A Pocket Common-place Book. With Locke's Index. Cheaper Edition. Post 8vo, strongly half-bound 6s. 6d.

DRAWING, &c.

LINEAL Drawing Copies for the Earliest Instruction. Comprising 200 subjects on 24 sheets, mounted on 12 pieces of thick pasteboard. By the Author of "Drawing for Young Children." In a portfolio. 5*s.* 6*d.*

Easy Drawing Copies for Elementary Instruction. By the Author of "Drawing for Young Children." Set I. Twenty-six Subjects mounted on pasteboard. Price 3*s.* 6*d.*, in a Portfolio. Set II. Forty-one Subjects mounted on pasteboard. Price 3*s.* 6*d.*, in a Portfolio.

*** The Work may also be had (two sets together) in one Portfolio, price 6*s.* 6*d.*

Drawing Models. Consisting of Forms for Constructing various Buildings, Gateways, Castles, Bridges, &c. The Buildings will be found sufficiently large to be drawn from by a numerous Class at the same time. In a Box, with a small Treatise on Drawing and Perspective. Price 2*l.* 10*s.* Length of the Box, 18½ inches; breadth 13 inches; height 8½ inches.

Drawing Materials. A Quarto Copybook of 24 leaves, common paper, 6*d.* A Quarto Copybook of 24 leaves, paper of superior quality, 1*s.* 3*d.* A Quarto Copybook of 60 leaves, 1*s.* 6*d.* Pencils, with very thick lead, B.B.B. 2*s.* per half-dozen. Pencils, with thick lead, F. at 1*s.* 6*d.* ditto. Drawing Chalk, 6*d.* per dozen sticks, in a Box. Port-crayons for holding the Chalk, 4*d.* each.

Perspective. Its Principles and Practice. By G. B. MOORE. In two parts, Text and Plates. 8vo, cloth, 8*s.* 6*d.*

The Principles of Colour applied to Decorative Art. By G. B. MOORE, Teacher of Drawing in University College, London. Fcap. 2*s.* 6*d.*

SINGING.

THE Singing Master. People's Edition. (One-Half the Original Price.) Sixth Edition. 8vo. 6*s.* cloth lettered.

"What chiefly delights us in the 'Singing Master' is the intermixture of many little moral songs with the ordinary glees. These are chiefly composed by Mr. Hickson himself; and we could scarcely imagine anything of the kind better executed. They relate to exactly the class of subjects which all who wish well to the industrious orders would wish to see imprinted on their inmost nature—contentment with their lowly but honourable lot, the blessings that flow from industry, the fostering of the domestic affections, and aspirations for the improvement of society."—*Chambers' Journal.*

*** *Sold also in Five Parts, any of which may be had separately as follows:—*

FIRST LESSONS IN SINGING AND THE NOTATION OF MUSIC. Containing Nineteen Lessons in the Notation and Art of Reading Music. 8vo, 1*s.* sewed.

RUDIMENTS OF THE SCIENCE OF HARMONY OR THOROUGH BASS. 8vo, 1*s.* sewed.

THE FIRST CLASS TUNE BOOK. A selection of thirty single and pleasing airs, arranged with suitable words for young children. 8vo, 1*s.* sewed.

THE SECOND CLASS TUNE BOOK. A selection of Vocal Music adapted for youth of different ages, and arranged (with suitable words) as two and three-part harmonies. 8vo, 1*s.* 6*d.*

THE HYMN TUNE BOOK. A selection of Seventy popular Hymn and Psalm Tunes, arranged with a view of facilitating the progress of children learning to sing in parts. 8vo, 1*s.* 6*d.*

The words without the Music may be had in three small books as follows:—

MORAL SONGS, from the FIRST CLASS TUNE BOOK. 1*d.*
MORAL SONGS, from the SECOND CLASS TUNE BOOK, 1*d.*
HYMNS from the HYMN TUNE BOOK, 1½*d.*

*** The Vocal Exercises, Moral Songs, and Hymns, with the Music, may also be had, printed on Cards, price Twopence each Card, or Twenty-five for Three Shillings.

BRADBURY AND EVANS, PRINTERS, WHITEFRIARS.

BOUND BY
EDMONDS & REMNANTS
LONDON